

# COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 5, No. 10

APRIL, 1934

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Gilbert Station, Holland, New Jersey

**Performance of the Gilbert Station**

**Heat Cycles and Their Relative Efficiencies**

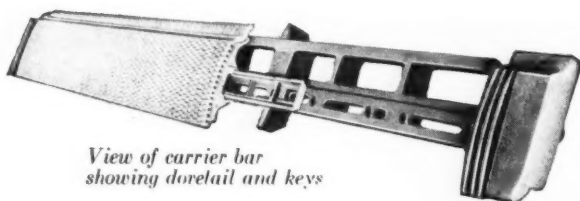
# MODERN STEAM PLANT EQUIPMENT

No. 2 of a series presenting design and operating features of C-E products

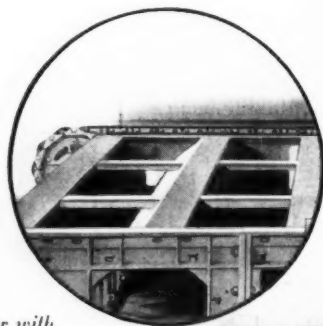
## COXE TRAVELING GRATE STOKER



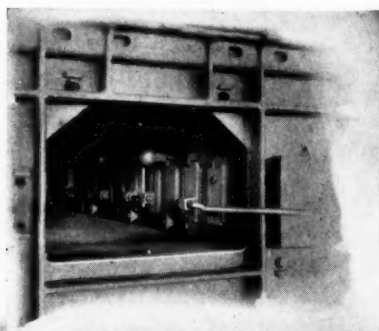
Front view of stoker including front air connection.  
Take-up mechanism shown at left side of grate



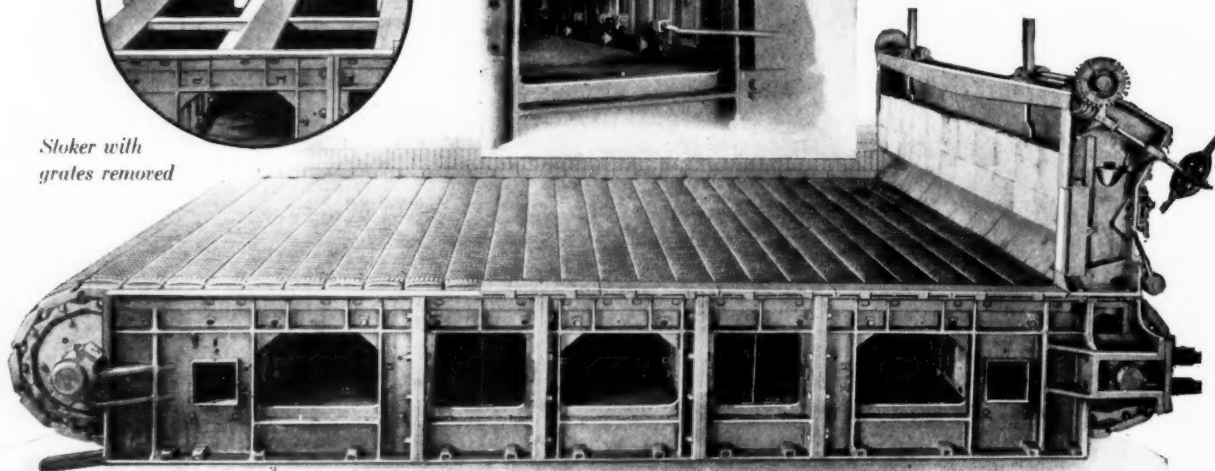
View of carrier bar  
showing doretail and keys



Stoker with  
grates removed



Windbox with grid  
dampers and operating rod



Side view of stoker showing grates and hopper in place

For small sizes of anthracite and coke breeze, lignite and certain non-caking bituminous coals.

### FEATURES

**Hopper . . .** Built of cast-iron and steel. Large capacity. Adjustable gate with tile protected from abrasion and moisture. Openings in feed plate provided for slicing clinker from side walls at fuel line. Index shows height of gate.

**Grate Surface . . .** Consists of non-sifting, cast-iron keys mounted on cast-iron carrier bars; not a chain grate. Overlapping construction of keys prevents ash being carried back to front of stoker.

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**Air Control . . .** Obtained by means of forced draft zones, front to rear. Damper operating mechanism conveniently located at side of setting.

**Easy Operation . . .** Assured by convenient location of all controls.

Over 10,000,000 sq. ft. of boiler heating surface has been equipped with Coxe Stokers.

A-130

## COMBUSTION ENGINEERING COMPANY, INC

200 Madison Avenue, New York, N. Y. . . . Canadian Associates, Combustion Engineering Corporation, Ltd., Montreal

# COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

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VOLUME FIVE

NUMBER TEN

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CHARLES McDONOUGH, *Editor*  
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# EDITORIAL

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## Questionable Economics

The National Coal Association has vigorously protested against the policy of the Federal Government in financing and promoting huge hydroelectric projects as a part of the Public Works Program. While these projects will afford employment to construction labor for a limited time, it is contended that thousands of miners will be thrown out of employment, and both the coal industry and the railroads will be adversely affected.

Another serious aspect of the case is the questionable soundness of the economics involved. To the lay mind, and especially those politically minded, water power and "cheap power" are synonymous. If the initial cost, representing the taxpayers' money, be disregarded (which would be unsound) this may be true—although not always, when transmission costs and electrical losses are included. Most of the sites reasonably close to existing markets have already been developed. Hence, there remains the alternative of creating markets within economical transmission distances of the remaining sites or promoting competition with existing steam plants in industrial centers, many of which can produce electricity cheaper than hydro energy can be delivered, when proper changes are included.

Justification for the Government's course will be found only in those projects which form the nucleus of large social regional developments on a scale that is beyond the scope of private endeavor, such as the T.V.A. where a large investment in hydro development had already been made.

## Relation of the Naval Program to Industry

Naval engineering is generally regarded as a highly specialized subject; yet its many ramifications and the work involved in bringing the Navy up to Treaty strength will reach out into numerous industries and utilize both the talent and the research of a vast number of engineers in civil life. This fact was ably brought out by Admiral W. H. Standley, Chief of Naval Operations, in an address at the recent dinner of the Society of Naval Engineers in Washington.

"It is the Navy's duty," said Admiral Standley, "to take the fullest advantage of all the research and development stimulated by commercial demands by adapting these developments to the solution of Naval problems. . . . It is always more than glad to cooperate with private concerns in the study of special problems, research or the development of special apparatus and material. . . . The Navy itself undertakes detailed design only to the extent that is absolutely necessary, but the field is so vast that all of the available facilities of our national industries must be used to the very maximum."

The Admiral ventured the opinion that in building a cruiser, for example, there are involved the efforts of as

many civilian engineers as there are officers in the entire Navy. In this estimate he was probably conservative.

"Our Navy," he said, "can be no better than the engineers who design and build it. It can advance no faster nor further than their visions and the ability to make those visions real. A Navy, or a ship, like the chain, is no stronger nor better than its weakest link. Who can say what branch of engineering bears the greatest responsibility, and who can predict whether a battle is to be won or lost because of superiority or inferiority of the main engines, the boilers, electrical apparatus, fire control instruments, gun liners, armor, navigational instruments, or what not?"

The present Naval program, including vessels now under construction, calls for approximately one hundred and sixty ships of all classes; in addition to which the replacement program, under the Treaty, calls for laying down from fifteen to twenty vessels annually. The effect of such a program will be felt in many industries and assist greatly in extending employment through a vast number of contractors and sub-contractors.

The Admiral's remarks serve not only to drive home these facts but also to impress upon the engineering fraternity the responsibilities which they share in our problem of national defense.

## Steam Cycles

Looking back over the past ten years one becomes conscious of greater and more intensive progress and refinements in power-plant practice than that represented by the accumulative effort of preceding years, if we except, perhaps, the influence of certain pioneer developments. During this period a succession of heat cycles have been employed, involving, first, progressively increasing steam pressures, and then, as materials became better understood, increasing steam temperatures. The higher temperatures and moderate pressures are being regarded with favor at present as a means of avoiding reheating, while maintaining cycle efficiency.

In this connection, two articles in this issue of COMBUSTION are especially pertinent. That by Mr. Rosenkrantz analyzes the several cycles employed during the past ten years and visions practice tending toward a cycle using steam at 800 lb and about 925 F. This cycle equals the efficiency of the high-pressure gas-reheat cycle, is simple, and less expensive to install. The second article, that by Mr. Powell, reviews the very excellent performance of the Gilbert Station which is a 1350-lb, 750-deg plant operating on the reheat cycle.

It is likely that the next two or three years will see many high-pressure units superimposed or existing low-pressure installations, both in central-stations and in industrial plants, this being an effective way to modernize many of the older plants.

The subject is one of particular importance at this time and further discussion is invited.

# Performance of the Gilbert Station

## Including Results of Week's Test

On a week's test under normal operating conditions an average heat rate of 11,960 Btu and 0.864 lb of coal per kw-hr, with a corresponding overall thermal efficiency of 28.55 per cent, was obtained. The average boiler-unit efficiency was 84.7 per cent. The performance of this 1350-lb station for nearly four years is included and compared with the low-pressure stations on the system. The operating continuity is also discussed.

GILBERT STATION was one of the first 1350-lb stations designed to operate regularly on variable loads. It was built in 1929 and was described at the time in the engineering press.<sup>1</sup> Therefore, only certain features of its design will be reviewed as having bearing on its subsequent performance and to refresh the memory of the reader. It is the most easterly of several steam and hydroelectric generating stations supplying the Pennsylvania-New Jersey System and is located at Holland on the east bank of the Delaware River about 15 miles below Easton. The supply of condensing water is ample, and a branch of the Pennsylvania Railroad

<sup>1</sup> Descriptions of the Gilbert Station were published in the *ELECTRICAL WORLD*, March 2, 1929; *POWER*, March 28, 1929; *GENERAL ELECTRIC REVIEW*, February, 1929; *POWER PLANT ENGINEERING*, March 1929. The first published account of its operation, covering the first six or eight months, was presented in a paper by E. M. Gilbert before the American Society of Mechanical Engineers and printed in *MECHANICAL ENGINEERING* for December 1930; and an article in *ELECTRICAL WORLD* of November 26, 1932, entitled "21½ Years' Experience with 1350-lb Steam Plant," showed that the major difficulties in the use of a working steam pressure of 1350 lb were, after all, not very numerous, and were responsible for a much smaller proportion of the total outage than were the troubles common to lower pressure plants whose details had been standardized for many years.

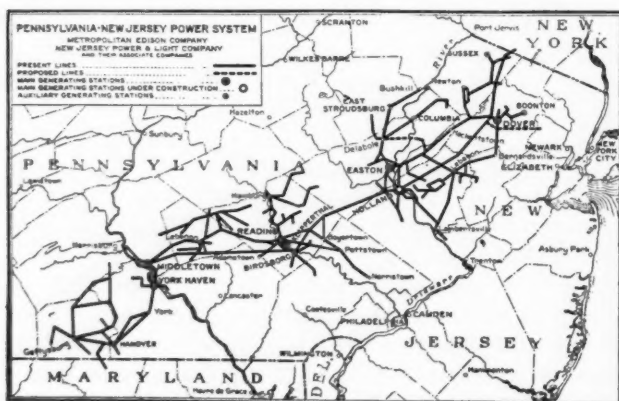


Fig. 1—Map of Pennsylvania-New Jersey Power System showing location of generating plants

By JAMES A. POWELL Vice-President  
E. M. Gilbert Engineering Corporation

System provides all transportation for fuel. But as the freight rates are higher than at Middletown and Reading on account of the longer haul from the coal mines, there was justification for a greater investment in the various devices for reducing to an economic minimum the consumption of fuel per kilowatt-hour.

Another factor in the economics of design of the Gilbert Station was the determination to make this the primary load plant for the system, ordinarily carrying throughout each 24-hr week-day period a fairly constant load, with maximum obtainable fuel economy, the morning and evening peaks above its capacity being carried on the older plants of the system. The station was therefore designed for long and steady continuous runs, generating the greater part of the power output of the system, and thus providing an incentive for refinement of economic planning that a designer cannot usually afford if the plant to be designed has a low load factor.

At the time the station was planned and built, the cost of coal delivered was about \$5.00 per ton of 2,000 lb. The cost of extracting the heat from the coal and converting it into kilowatt-hours was thus referred to a coal price of \$5.00 per ton; that is to say, selection of the boilers, furnaces, superheaters, turbines, condensers and all the accessory heat exchanging devices was on the basis of whether or not the value of the heat units in the coal at this price, which these devices would save, would justify their respective costs.

### Station Design

The ultimate design of the Gilbert Station comprises four 55,000-kw turbine-generators of the cross-compound type, each supplied with steam by two boilers each capable of evaporating 250,000 lb of steam per hour at 1350 lb pressure. Only the first unit has thus far been installed. This was placed in service on March 2, 1930. Fig. 2 shows a cross-sectional elevation of the initial station. It will be noted that there is no partition between the turbine and boiler rooms, a comparatively new feature of design, at the time, which facilitates supervision of both turbines and boilers with few operators.

### Status of Gilbert Station in the System

Other steam plants owned and operated by the system (see Fig 1) are the West Reading Station of 69,000 kw and the Middletown Station of 65,000 kw, the latter being the more modern and economical of the two and



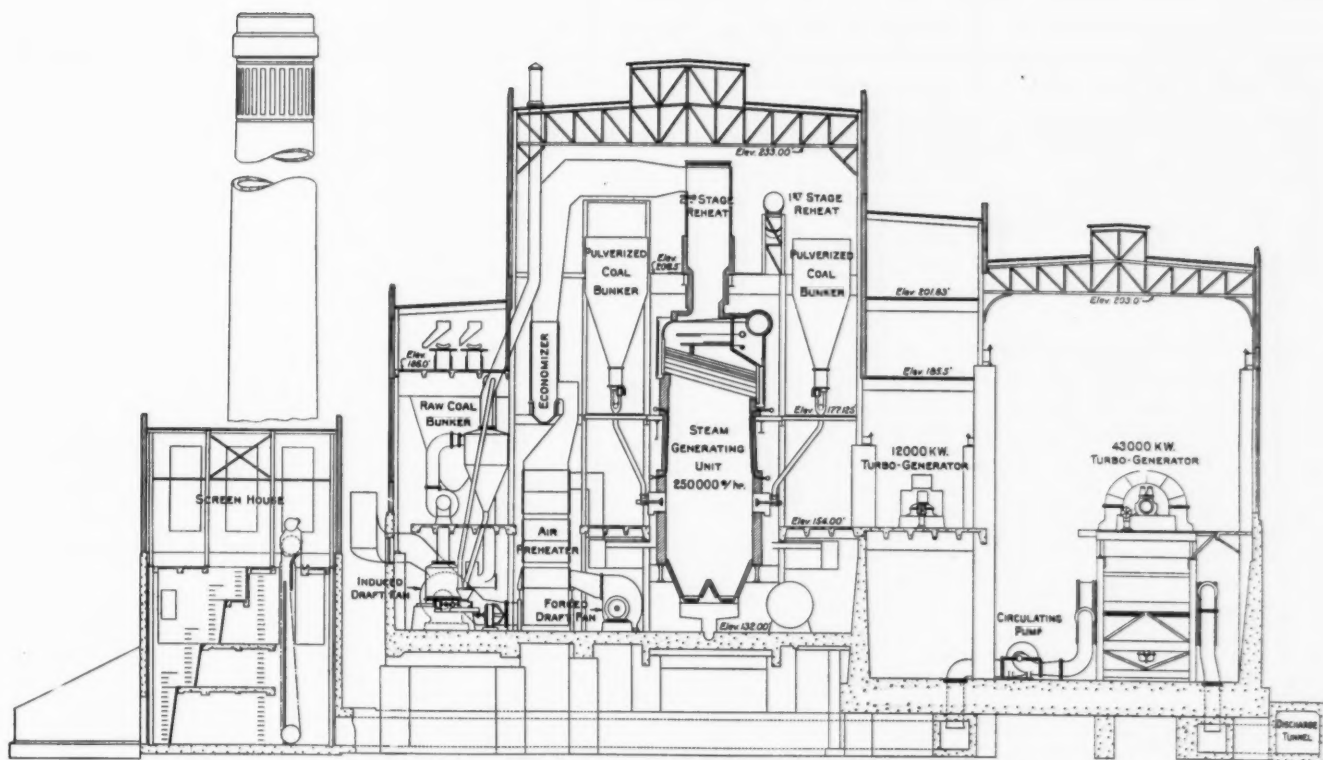


Fig. 2—Cross-sectional elevation of station

nearly always in operation. The former is used chiefly as a standby to carry peaks when the Middletown plant is loaded to capacity. The Gilbert Station commonly carries the primary load of 45,000 to 55,000 kw continuously except during week-ends. Besides the foregoing, there are interconnections with neighboring systems on the north, east and south totaling about 135,000 kw if all were called into service to their full interconnection capacity; but usually not more than one-quarter to one-third of this is exchanged at any one time. Generally speaking, the System sells more power through these interconnections than it purchases from them. The present system generation is a little under 800,000,000 kwhr per year, of which about 300,000,000 kwhr is generated by the Gilbert Station.

#### *Operating Test of November, 1933*

With the foregoing facts in mind regarding the purpose and the design of the Gilbert Station, it will be of interest to follow through a test of its operation in regular service to check its actual against its predicted performance.

The station was under test for a period of 168 hr, from 12:01 a.m. Sunday, November 19 to midnight Saturday, November 25. The intent of this seven-day test was to determine, after four years of regular use, the general efficiency of the entire station in regular consecutive day-to-day operation, without any preliminary cleaning or tuning up of any part of the equipment, for it was not desired to attempt any maximum or special results which would not ordinarily be duplicated thereafter. A preliminary 72-hr trial was conducted for the sole purpose of checking the accuracy of indicating and recording instruments, and to get the observers familiar with the station routine and their own duties as affected thereby. The observers were from the regular testing department staff of the Utilities Management Corporation.

#### *Coal Measurement*

The coal levels in the bunkers were estimated at the start and at the finish of the test. The error involved in this estimation might be 25 tons more or less, which is equivalent to less than 1 per cent of the total used. No attempt was made to estimate the coal levels every day, but the daily coal and Btu consumption reported on Fig. 3 are calculated from the total steam generated, assuming the average evaporation rate obtained during the week's run. Of the total coal used, 42.5 per cent was unloaded directly from cars and 57.5 per cent was taken from storage. In order to take care of the shrinkage of the storage coal, 55 tons were added to the weight records from the weightometer readings. This amount, which represents 1.9 per cent of the total consumed, is included in the "radiation and unaccounted-for losses" obtained by difference in the heat balance shown in the summary of boiler operation, Fig. 4. The coal escaping through the mill vents, which was estimated at about 0.5 per cent, is also included in this item. During the test period, there was only one starting-up of a boiler, and the 16,500 lb of fuel used for this boiler start, are deducted from the total amount consumed.

#### *Operating Conditions*

No abnormal conditions were encountered during the entire week. There were no interruptions to any piece of equipment to disturb the regular routine. No effort whatever had been made prior to the test, to bring about special conditions of cleanliness, either of the boilers or of the condenser. Throughout the test the station was carrying the base load for the system. Fig. 5 illustrates the energy delivery for each hour of the entire test by both the low-pressure and the high-pressure units together, and by the high-pressure unit separately.

Fig. 6 presents, in self-explanatory diagrammatic form, the percentages of heat utilized for energy con-



Items	Unit	Nov.19	Nov.20	Nov.21	Nov.22	Nov.23	Nov.24	Nov.25	Total
<b>Total Quantities</b>									
Duration of Test	Hrs.	24	24	24	24	24	24	24	168
Generation High Pressure Unit	K.W.H.	159000	222000	250000	246000	246000	244000	179000	1546000
Generation Low Pressure Unit	K.W.H.	439000	884000	968000	954000	954000	935000	495000	5629000
Total Generation	K.W.H.	598000	1106000	1218000	1200000	1200000	1179000	674000	7175000
Station Use	K.W.H.	48580	70060	74240	74050	73840	74630	51770	467170
Net Output	K.W.H.	549420	1035940	1143760	1125950	1126160	1104370	622230	6707830
Steam Generated	Lbs.	4509740	8663180	9569200	9508120	9467400	9385960	5212160	56315760
Make Up	Lbs.	13795	27590	27590	27590	27590	27590	13795	165540
Water Supplied to Boiler	Lbs.	4523535	8690770	9596790	9535710	9494990	9413550	5225955	56481300
Condensate from Condenser	Lbs.	3780000	6920000	7580000	7380000	7520000	7340000	4180000	44700000
Steam for Bleeding & Glands	Lbs.	729740	1743180	1969200	2128120	1947400	2045960	1032160	11615760
<b>Hourly Quantities &amp; Avg. Values</b>									
Generation High Pressure Unit	K.W.H.	6630	9250	10420	10250	10250	10160	7460	9200
Generation Low Pressure Unit	K.W.H.	18300	36900	40380	39750	39750	39000	20640	33510
Average Generation	K.W.H.	24930	46150	50800	50000	50000	49160	28100	42710
Average Station Use	K.W.H.	2020	2920	3090	3080	3080	3110	2160	2850
Average Output	K.W.H.	22910	43230	47710	46920	46920	46050	25940	39860
Steam Generation	Lbs.	187800	360800	398600	396000	394400	390800	217000	335000
Condensate from Condenser	Lbs.	157500	288300	315700	307400	313300	305700	174100	266000
Steam for Bleeding & Glands	Lbs.	30300	72500	82900	88600	81100	85100	42900	69000
Voltage Generation Leads	Volts								
Current Per Phase	Amp.	1057	2050	2235	2220	2180	2140	1220	1872
Power Factor	%	88	90	93	94	95	95	94	93
<b>Demands</b>									
Minimum 60 Minutes	K.W.H.	15000	15000	31000	30000	30000	33000	26000	15000
Maximum 60 Minutes	K.W.H.	29000	57000	57000	58000	57000	57000	29000	58000
Instantaneous	K.W.H.	29600	57200	57500	58200	57500	57200	29300	58200
Station Load Factor	%	45.3	83.8	92.3	90.9	90.9	89.3	51.0	77.6
<b>Average Pressure</b>									
Throttle	#/sq.in.	1250	1250	1250	1250	1250	1250	1250	1250
Barometer at Station	In.Hg.	29.70	29.80	29.94	29.72	29.80	30.06	30.18	29.91
Condenser Vacuum	In.Hg.	.55	.68	.71	.73	.73	.72	.68	.69
<b>Average Temperatures</b>									
Outside	°F	33	41	44	51	42	38	44	42
Turbine Room	°F	74	72	76	75	76	76	74	75
Cellar (Forced Draft Fans)	°F	74	80	90	82	76	83	85	82
Intake Water Temperature	°F	35.5	37.0	38.0	40.0	40.0	39.0	39.0	38.5
<b>Efficiencies</b>									
Relative	%	98.50	96.00	96.10	95.80	96.10	95.00	98.50	96.00
Thermal	%	29.16	28.65	28.65	28.35	28.50	28.16	28.60	28.55
Boiler Plant	%	84.70	84.70	84.70	84.70	84.70	84.70	84.70	84.70
Rankine Cycle Ratio	%	80.60	80.60	80.60	80.60	80.60	80.60	80.60	80.60
<b>Evaporation</b>									
Actual Steam / Lb. Coal	Lbs.	9.72	9.72	9.72	9.72	9.72	9.72	9.72	9.72
Equiv. Steam / Lb. Coal	Lbs.	10.41	10.41	10.41	10.41	10.41	10.41	10.41	10.41
<b>Coal Consumption</b>									
Per K.W.H. Generated	Lbs.	.776	.806	.808	.815	.812	.819	.796	.808
Per K.W.H. Output	Lbs.	.845	.861	.861	.869	.865	.875	.862	.864
<b>Heat Unit Consumption</b>									
Per K.W.H. Generated	B.t.u.	10742	11157	11185	11282	11241	11337	11019	11185
Per K.W.H. Output	B.t.u.	11697	11919	11919	12030	11974	12113	11933	11960
<b>Steam Consumption</b>									
Per K.W.H. Generated	Lbs.	7.54	7.83	7.85	7.92	7.89	7.95	7.73	7.85
Per K.W.H. Output	Lbs.	8.21	8.37	8.37	8.45	8.41	8.50	8.38	8.40
<b>Energy Consumption</b>									
Station Use to Plant Output	%	8.86	6.76	6.50	6.57	6.56	6.74	8.32	6.98
Coal Preparation to Plant Output	%								.71
<b>Miscellaneous Ratio</b>									
Make Up to Feed Water									.293
<b>Fuel Analysis</b>									
Moisture	%								3.84
Volatile	%								20.41
Fixed Carbon	%								67.47
Ash	%								8.28
Heat Value As Fired	B.t.u.								13843
Heat Value Dry	B.t.u.								14395
<b>Fuel Consumption</b>									
Coal Total	Lbs.	464013	906974	984586	978302	974112	965734	536279	5610000
Coal for Starting Boilers	Lbs.		15600						15600
Coal for Starting Turbines	Lbs.								
Coal for Electric Generation	Lbs.	464013	891374	984586	978302	974112	965734	536279	5794400
Kind of Coal			Mixture of Cambria - Portage - Brookwood - Banner						

Fig. 3—Summary of results of station operation for week's test

Items	Units	Boiler 1	Boiler 2	Total
<b>Hourly Quantities</b>				
Coal Burned in Furnaces	Lbs.	20 000	20 780	
Coal Burned per Burner	Lbs.	3 334	3 460	
Steam Flow (Red Pen Reading)	Lbs.	194 500	204 000	
Air Flow (Blue Pen Reading)	Lbs.	194 500	204 000	
Actual Evaporation	Lbs.	9.72	9.72	9.72
Factor of Evaporation	Lbs.	1.082	1.082	1.075
Equiv. Evap. Per Lb. Coal	Lbs.	10.50	10.37	10.41
Equiv. Evap. Per Hour	Lbs.	208 800	217 000	
B.t.u. Liberated Per Hour				
Per Cu.Ft. of Furnace	B.t.u.	15 250	15 800	15 525
<b>Efficiencies</b>				
Boiler, Spht., W.Wall & Air Preh.	%	11.70	11.70	63.50
Gas Reheater	%			11.70
Economizer	%			9.50
<b>Heat Balance in %</b>				
Heat Abs. by Boiler, Reheater, Economizer & Air Preheater	%	84.79	84.66	84.70
Loss Due to Dry Flue Gases	%	5.85	5.98	5.94
Loss Due to Comb. in Flue Ash	%	.25	.22	.23
Loss Due to CO	%	0.00	0.00	0.00
Loss Due to Moisture in Coal	%	.32	.32	.32
Loss Due to Moisture in Air	%	.08	.09	.08
Loss Due to Hydrogen	%	3.18	3.18	3.18
Loss Due to Radiation & Unacc. For	%	5.55	5.55	5.55
<b>Heat Balance in B.t.u.</b>				
Heat Abs. by Boiler, Reheater, Economizer & Air Preheater	B.t.u.	11 736	11 720	11 725
Loss Due to Dry Flue Gases	B.t.u.	810	827	822
Loss Due to Comb. in Flue Ash	B.t.u.	34	30	32
Loss Due to CO	B.t.u.	0	0	0
Loss Due to Moisture in Coal	B.t.u.	44	44	44
Loss Due to Moisture in Air	B.t.u.	8	13	11
Loss Due to Hydrogen	B.t.u.	440	440	440
Loss Due to Radiation & Unacc. For	B.t.u.	769	769	769
<b>Ratios of Heat Absorption</b>				
Boiler & Water Walls	%			48.90
Superheater	%			13.20
Air Preheater	%			12.80
Gas Reheater	%			13.80
Economizer	%			11.30
Total	%			100.00

Fig. 4—Summary of results of boiler operation for week's test

version, and rejected through the various inevitable channels of station waste, per net kilowatt-hour on the station bus bars.

The average relative efficiency, based on gross kilowatt-hours generated, was 96 per cent; which means that the operating test showed that the running efficiency throughout the entire week measured up to 96 per cent of the guaranteed efficiency of the various units composing the station equipment.

The quantities, temperatures and pressures from which are calculated the efficiencies and unit consumptions of coal, heat units, steam and station-use energy are set out in Fig. 3. From these figures, the station heat balance was computed.

#### Gilbert Station Compared with West Reading and Middletown Stations

Comparative figures on stations operating at various

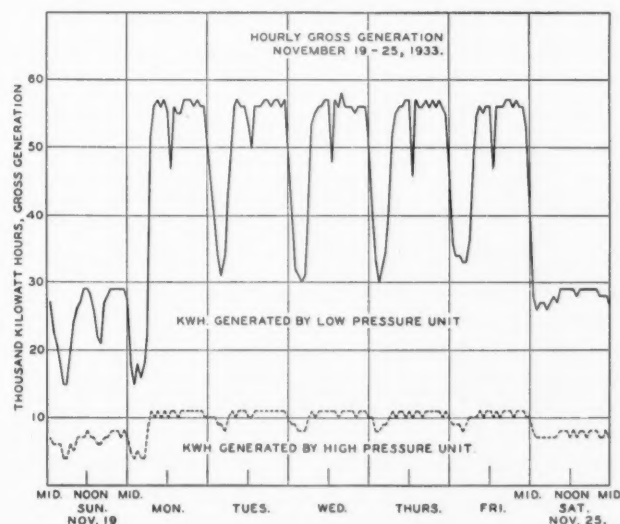


Fig. 5—Energy delivered for each hour of test

pressures and indicating the savings progressively realized during the past decade of power plant evolution, are always interesting. The West Reading station was first placed in operation in 1919 at 200 lb boiler pressure, and enlarged in 1924 when the boiler pressure was raised to 265 lb. The Middletown Station on the Susquehanna River was first started in 1925 at 348 lb boiler pressure and enlarged at the same pressure in 1926. The Gilbert Station was started in 1930, with 1350 lb at the boilers and 1250 lb at the turbine throttle.

Having data available from actual test runs at these two older stations, it is thought worth while to include in this report, a table summarizing the information collected in these tests at lower steam pressures, for comparison with the results of the 1350-lb station herewith presented. Each of these tests was conducted over a

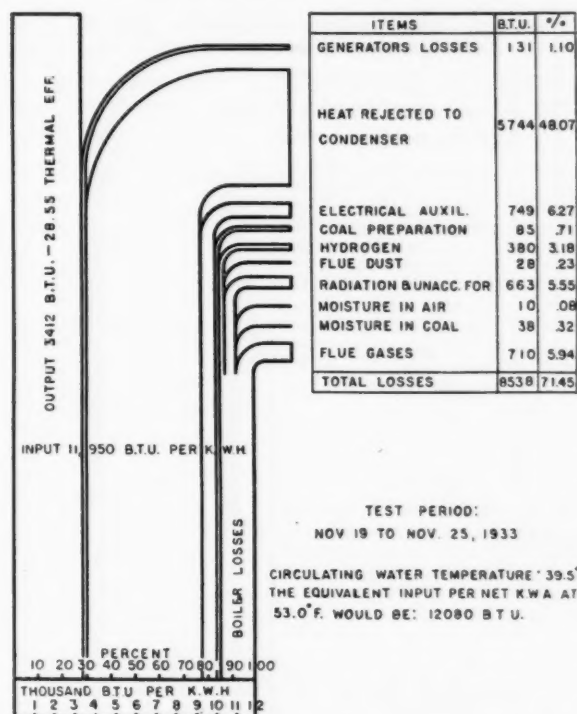


Fig. 6—Heat-flow diagram for test period

period of about one week's duration, the same as for the present test of Gilbert Station. Each of these two older stations represented first-class practice at the time it was built. Progress in utilization of the heat energy in the coal, can be briefly summed up in the following comparison:

Plant	Throttle pressure	Year	Btu per net kwhr	Lb coal per net kwhr	Overall thermal efficiency per cent
West Reading	190	1919	29,510	2.16	11.54
West Reading	250	1924	19,380	1.39	16.41
Middletown	325	1925	15,711	1.138	21.72
Gilbert	1,250	1933	11,960	0.864	28.55

These three stations have all been designed and built, and their operations watched, by the E. M. Gilbert Engineering Corporation, formerly W. S. Barstow & Company, of Reading, Pa. and represent their long series of contributions to advancement in the art of generating electric power from coal, with progressive improvement in the efficiency of energy conversion. The three stations above mentioned now constitute the sole sources of steam-generated power in the Pennsylvania-New Jersey

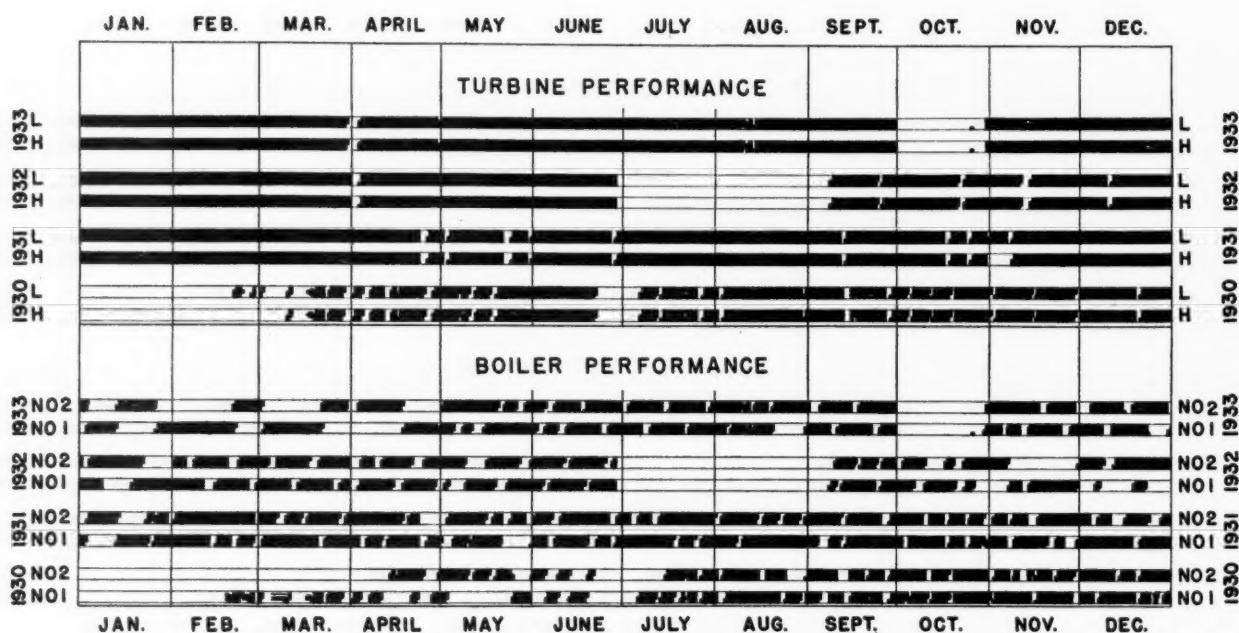


Fig. 7—Operating continuity from March 1930 through December 1933

group of utilities of the Associated Gas & Electric Company, several smaller and older stations having been rendered obsolete and shut down during the past 14 years. These older stations were located at Hanover, Lebanon and Easton, Penna., and Dover, N. J. In 1920, the West Reading station as then constituted, represented first-class engineering construction, while the other stations were of long previous vintage and have since been replaced by the Middletown and Gilbert Stations. It will be of interest to note the gradual diminution of the system coal rate in pounds per kilowatt-hour, in these steam generating stations of the Pennsylvania-New Jersey group, throughout the past 14 years, as shown by the following figures:

1920—2.638	1927—1.410
1921—2.583	1928—1.426
1922—2.608	1929—1.443
1923—2.441	1930—1.273
1924—1.914	1931—1.211
1925—1.659	1932—1.275
1926—1.552	1933—1.156

#### Summary

In stepping up the boiler pressure to 1350 lb for the continuous operation of a whole new base-load station, the designers were blazing a pioneer trail. A few months of preliminary operation gave opportunity to appraise the special troubles incidental to the use of 1350-lb steam, and to overcome them effectively.

The chart in Fig. 7 of operating continuity from the very beginning in March, 1930, shows that subsequent to June 1930 (when the plant was overhauled after the initial "shaking-down" period), there were no important major interruptions to service for almost two years, when a 72-day break in continuity occurred, due to an accident to the blading of the 400-lb turbine unit, such as has happened occasionally in many a large 200 to 400-lb station. Many of the other outages shown on the chart are week-end shutdowns ordered by the system load dispatcher. For the period of exactly two years from July 7, 1930 to July 7, 1932 (which overlapped 9 days into the 72-day outage) the availability of the station was 93.8 per cent.

Such troubles as have been solely due to the 1350-lb pressure, have been responsible for a much smaller proportion of the total outage than have the troubles common to all low-pressure plants. Dangers which are ever present in large low-pressure turbines are not present to the same degree in the 1350-lb turbine unit at the Gilbert Station. The economic reasons for the selection of 1350-lb are just as valid now as when the plant was designed.

The low heat unit cost of about 12,000 Btu per net kilowatt-hour is most advantageous in the daily interchanges of secondary power with other utility companies. That it is both continuous and dependable may be seen from Fig. 7. In Fig. 8 are shown graphically the limits of variation of the station load factor, the kilowatt-hour generation, and the Btu per kilowatt-hour, for nearly four years, indicating that a high economic efficiency is a matter of continuous accomplishment.

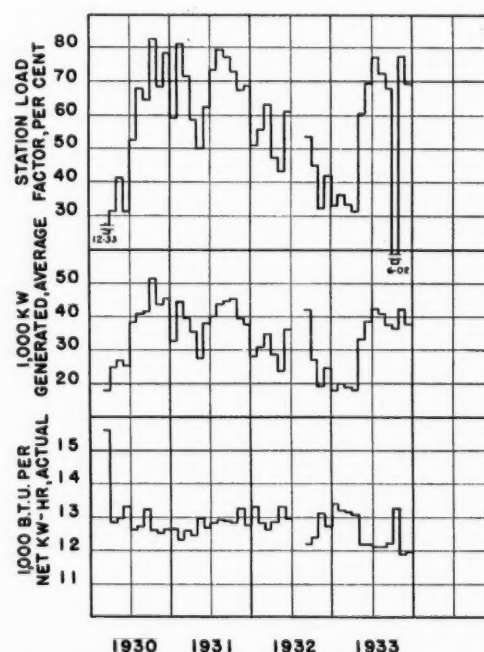


Fig. 8—Output, load factor and Btu per kw-hr



# Heat Cycles and Their Relative Efficiencies

The original article by the writer on the above subject appeared in the May 1931 issue of COMBUSTION. The present article reviews progress subsequent to that date and adds supplementary comments. Engineering opinion is now being focused on a non-reheat cycle employing pressures around 800 lb and temperatures of 925 F. The advantages of this cycle are discussed.

○ F THE cycle diagrams B, C, D and P shown herewith, B, C and D appeared in the original article. The comments associated with diagram B have not been altered but those associated with C and D have been altered and brought into harmony with current thought. Diagram P illustrates a cycle which is immediately before us and for which equipment is available. The cycle, however, has not been adopted in any specific instance. It will be observed by reference to Table I that the overall economy of Cycle P equals and in fact, slightly surpasses that of Cycle D for the 1200-lb pressure, gas-reheat cycle. It will further be observed by reference to Table I of the original article, here reproduced as Table I-a that the heat consumption of 11,500 Btu per kw-hr output for Cycle D closely approaches the economy of 11,010 Btu per kw-hr output for the mercury-steam cycle (E) employing a water-cooled furnace. It, of course, falls considerably short of the economy of the mercury-steam cycle G employing an all mercury cooled furnace, a development which, however, has not yet been achieved.

Since publication of the original article in 1931, a number of plants operating on Cycle C, with 600 to 800 lb pressure and steam temperatures up to 860 F, have either been placed in operation or are nearing completion. Thus far, no difficulties have developed which are in any way associated with the high temperature. The first of the 20,000-kw mercury plants has been in operation for a period of something over one year and the second for a period of several months. Descriptions of these plants have been made available to the public but thus far nothing has been published covering the performance or operating experience. The 10,000-kw, 1000-deg temperature installation of the Detroit Edison Company has been in service for a considerable period and the performance and operating experiences made

<sup>1</sup> "High-Pressure Steam Experience at Detroit" by P. W. Thompson and R. M. Van Duzer, Jr. and "The Thermal Performance of the Detroit Turbine Using Steam at 1000 Deg. Fahr." by W. A. Carter and F. O. Ellenwood. These were published in the November and December 1933 issues of COMBUSTION.

By H. F. ROSENCRANTS

Advisory Engineer

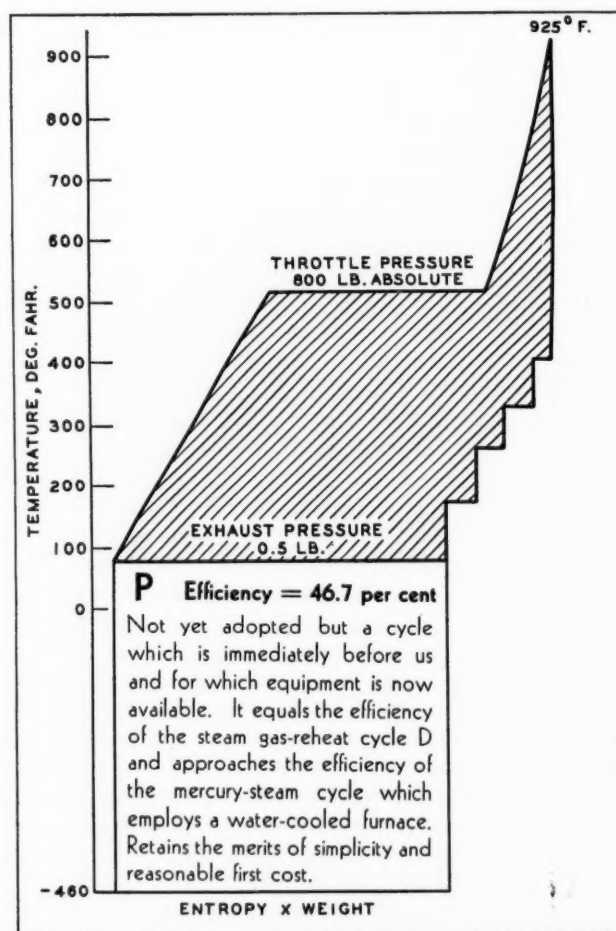
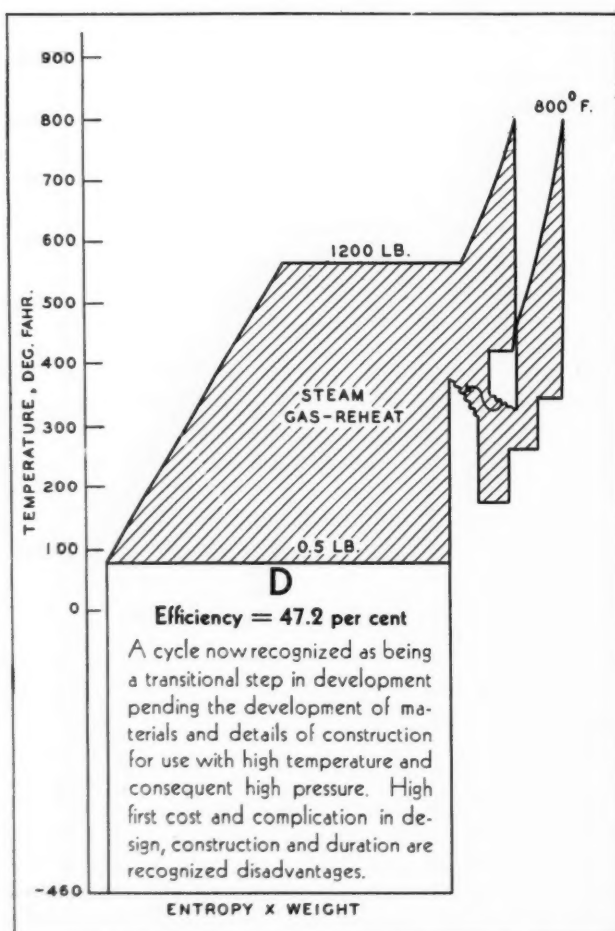
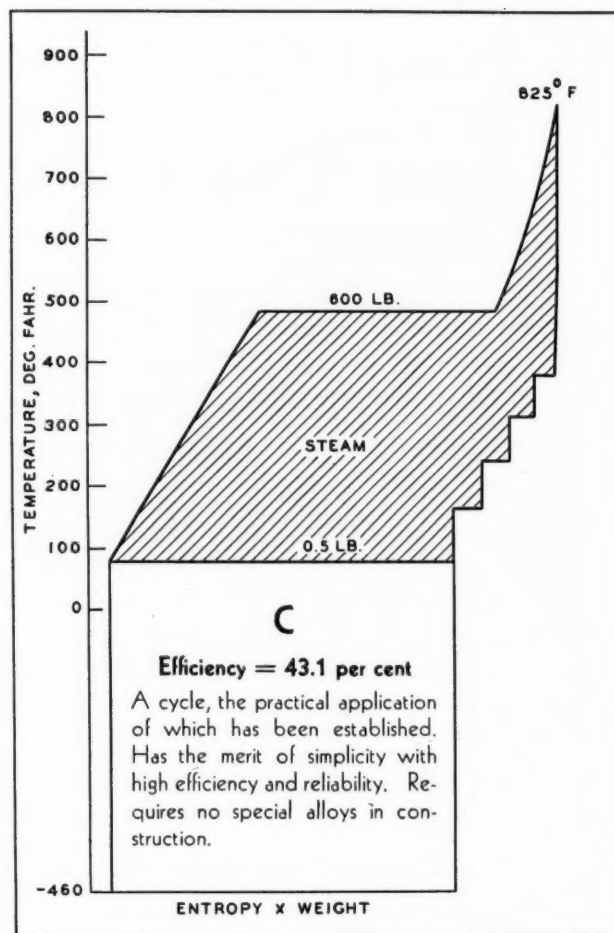
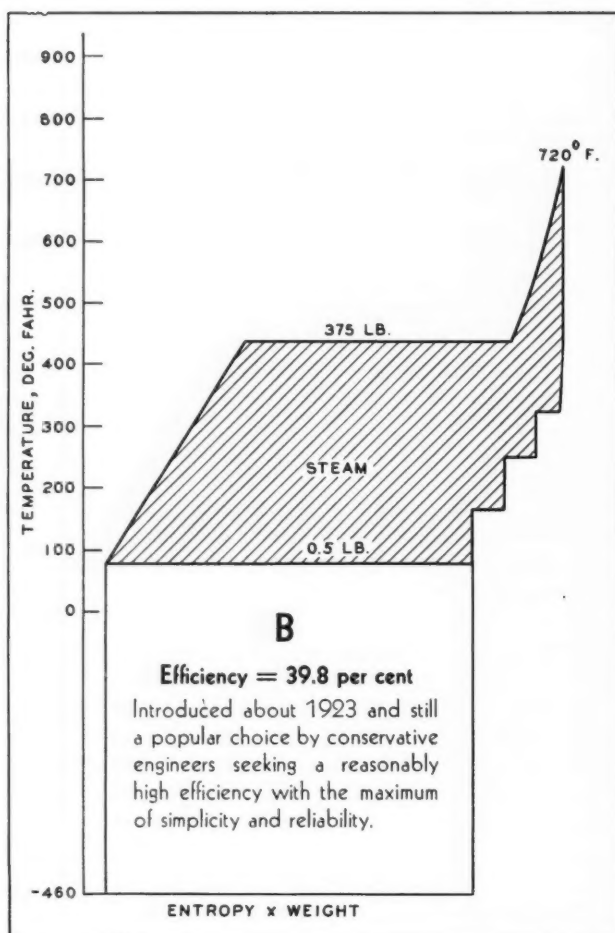
Combustion Engineering Company, Inc.

available to the public in two very excellent papers<sup>1</sup> presented at the December 1933, meeting of the A.S.-M.E. No additional plants operating on the high-pressure reheat cycle have been added to the list and, if the sentiment reflected by discussions at the December meeting of the A.S.M.E. may be used as a guide, it seems probable that few, if any, more plants will be purchased for operation on that cycle. Engineers appear definitely to have their eyes focused on plants operating on a cycle similar to that illustrated by Diagram P which has the merit of simplicity in design, construction and operation; has an efficiency equal to that of the 1200-lb pressure, gas-reheat 800-deg plant, and may be built at a cost only slightly exceeding that of the plant operating on Cycle C.

Construction facilities, processes and materials have been developed, tested out and adopted which make important reductions in the cost of construction of plants for high pressure and temperature. The general adoption of welded boiler drums and the recent approval by the A.S.M.E. Boiler Code of the use of high tensile steel makes possible the construction of cross-drum, sectional-header type boilers up to 1400-lb and bent-tube type of boilers up to 900 lb design pressure without going to the expense of forged-steel drums. These design pressures will permit operating pressures at the turbine throttle of approximately 1300 and 825 lb, respectively. For 925 F steam temperature, only moderately expensive alloys will be required for other than perhaps the last loop of the superheater units. The superheater headers, the high-pressure steam piping to the turbine and some parts of the high pressure end of the turbine unit will require something better than ordinary carbon steel but the cost of suitable alloys will not become an item of major importance.

The boiler units, including the superheaters, may be constructed with complete absence of any flanged joints. It seems probable that flanged joints should also be eliminated in the high-pressure steam piping from the boiler unit to the turbine. The progress in welding steam piping would appear to be keeping pace with requirements in this connection.

With the adoption of temperatures as high as contemplated by Cycle P a positive means of superheat control, to insure that under certain circumstances of operation the temperature will not go higher, will be required. Simple and reliable equipment is now available for the purpose. Equipment designed with excess of superheating surface and embodying intermediate



desuperheating with either air or water (preferably the former) as the cooling medium will be employed. So designed, a flat steam temperature curve may be maintained over an appreciable range at the high ratings. The value of this feature as reflected in plant economy in itself justifies a considerable portion of the cost.

TABLE I—PLANT EFFICIENCIES

Cycle	Cycle efficiency %	Turbine blade- ing efficiency, %	Turbo-genera- tor efficiency, %	Boiler plant efficiency, %	Aux. energy, % of generated	Overall plant efficiency, %	Btu consump- tion per kwhr output
B	39.8	80	96.5	87	4.65	25.5	13,370
C	43.1	80	96.5	87	4.84	27.6	12,340
D*	46.6	80	96.5	87	5.56	29.6	11,500
P	46.7	80	96.5	87	4.86	29.9	11,400

\* Assumes a loss of 0.6 per cent due to a 30-lb pressure drop through reheater hence difference in efficiency from that indicated on diagram D

The pressure and temperature contemplated by Cycle P render it admirably applicable for superimposing on existing plants operating at 250 lb pressure or less. This has been done in at least one important instance and is being seriously considered in a number of other cases.

TABLE I-a—PLANT EFFICIENCIES\*\*

Cycle	Cycle efficiency %	Turbine blade- ing efficiency, %	Turbo-genera- tor efficiency, %	Boiler plant efficiency, %	Aux. energy, % of generated	Overall plant efficiency, %	Btu consump- tion per kwhr output
A	35.4	80	96.5	87.0	4.75	22.65	15,050
B	39.8	80	96.5	87.0	4.65	25.50	13,370
C	43.1	80	96.5	87.0	4.84	27.60	12,340
D*	46.6	80	96.5	87.0	5.56	29.60	11,500
E	48.7	80	96.5	84.7	3.63	30.70	11,010
F	52.0	80	96.5	84.4	3.53	32.60	10,450
G	56.7	80	96.5	84.0	3.12	36.00	9460

\* Assumes 30-lb pressure drop through reheater hence difference in efficiency from that indicated on diagram D

\*\* Published in the May 1931 issue of COMBUSTION, page 21.

After expansion from 800 lb and 925 F to 250 lb with 80 per cent turbine blade efficiency the temperature of the steam is approximately 670 F. This is about as high as many existing turbines designed for 250 lb abs pressure will stand.

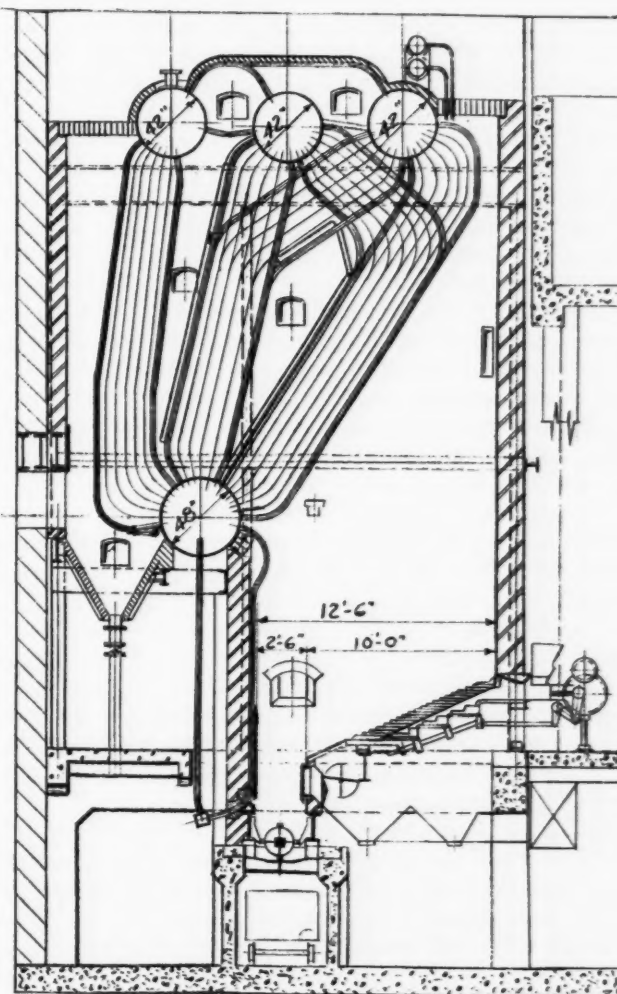
## Pulverizing Characteristics of Coal

The committee on coal and coke of the American Society of Testing Materials is making arrangements to conduct a round-robin series of tests on several different coals covering a wide range of hardness, using different methods of testing for grindability. There is considerable information available concerning the grinding characteristics of the coals selected, and once data are available from the tests, they will be studied and it is expected that the test which appears to be the most suitable will be standardized.

Wilbur G. Hudson has been appointed chief engineer of the Link-Belt Company's Pershing Road Plant in Chicago.

## Low Head Ashpit Arrangement for Clinker Grinder Stokers

The sketch shows a proposed arrangement for reducing the headroom requirements where it is necessary to provide a method for transporting ash from a clinker grinder type of multiple-retort stoker. Briefly the arrangement consists of providing a tunnel running under each clinker grinder. In this tunnel a car receives the ash discharging directly from the grinders. The ends of the tunnel, under the side walls of the boiler are closed by a door of either the roller or swinging type. An alternative arrangement would be a car which fits very closely underneath the clinker-grinder supporting and provided with clips or steel plates.



Section through boiler setting showing ash-disposal arrangement

Because a certain amount of ash may fall on the floor of the tunnel, thereby making it difficult to push a car along, it might be desirable in some cases to suspend the car from overhead rails. Where these rails were of an inconvenient height in the boiler room basement a combination type of car could be employed, which would hang from the overhead rail while under the clinker grinder and on wheels in the basement.

The arrangement makes unnecessary the provision of an overhead ashpit with its expensive gates and head room below the gates for the ordinary ash-disposal car.



# The Winkler Test for Determining Oxygen in Boiler Feed Water

By J. D. YODER and A. C. DRESHER  
The Cochrane Corporation, Philadelphia

THE Winkler method for determining oxygen in water was developed in 1888, since which date it has been the method most extensively used for this purpose. Its first use was for determining the dissolved oxygen in surface waters, which, if saturated have from 6 to 8 ml per liter, depending upon the temperature of the water.

Winkler recognized the limitations of his method in the presence of interfering salts such as iron, nitrites and organic matter and proposed modifications, which have been supplemented by others. The most common modification is the Rideal-Stewart, which is advocated by the American Public Health Association if the water contains nitrites. The Winkler method with its modifications as applied to surface water supplies is well discussed in U. S. Public Health Bulletin No. 151. This method, later set forth in detail, depends upon the setting free of iodine equivalent to the amount of oxygen in the sample by the addition of suitable reagents. The liberated iodine reacts with starch which is added to the sample as an indicator to give a characteristic and distinct blue color. Standard sodium thiosulphate solution is added from a burette to a measured sample which changes the iodine to sodium iodide and removes the blue color. The amount of sodium thiosulphate solution added to remove the blue color is a measure of the oxygen in the sample. The sensitivity of the iodo-starch reaction increases with decreasing temperatures.

Until the development of deaerating heaters for the protection of boilers, piping and economizers from oxygen corrosion, the water tested for oxygen was generally at atmospheric temperature, ranging from 70 to 90 F, so that the effect of temperature of the sample was not emphasized in the literature. Realizing that high temperatures impaired the sensitivity of the iodo-starch color reaction, the N.E.L.A. in its "Power Station Chemistry" serial report of the Prime Movers Committee, February 1929, recommended that if the sample had a temperature in excess of 120 F, it should be cooled before making the test. At that time manufacturers of deaerating heaters generally recommended that the sample should be cooled to 100 F at which temperature the iodo-starch color reaction was more sensitive.

Several years ago it was observed that at a number of plants where zero oxygen was found by the Winkler test as then advocated corrosion still contained particularly in steel-tube economizers. This showed the need of a more exact method of determining oxygen which led to our further study of the refinements

The March issue of COMBUSTION contained an article by Salvatore Alfano of the Houston Lighting and Power Company on "Factors Limiting Sensitivity and Accuracy of Test for Dissolved Oxygen" in which certain limitations of the Winkler test were discussed. In the present article the authors discuss the subject from a somewhat different angle and present the results of an investigation extending over more than a year in which various starches were studied. The refinements necessary to determine small quantities of oxygen in deaerated feedwater are pointed out.

necessary to determine more accurately small quantities of oxygen in deaerated boiler feedwater. It was found that with the precautions commonly taken the water might contain as much as 0.1 to 0.2-ml oxygen per liter and still show zero oxygen.

It is well here to observe that an accuracy of 0.1-ml oxygen per liter represents a comparatively high degree of accuracy for this is only 1½ per cent of the oxygen frequently present in surface water and is only 14 parts by weight in 100 million parts of water. This small amount, however, is sufficient to cause corrosion at high temperatures.

In this report attention is directed only to necessary precautions that have frequently been neglected in making the Winkler test. They relate chiefly to the following: 1. Kind of starch to use; 2. Temperature of sample tested; 3. Oxygen in reagents; 4. Interferences; 5. Method of sampling.

## Starches

Ten different starches were tested with results indicated in Tables I and II. In Table I the starches are arranged in their order of sensitivity at the higher temperatures. In Table II they are arranged in their order of solubility.

In determining the characteristics of various starches, the concentration of reagents added conformed with the concentrations regularly used in making the Winkler test and as detailed at the close of this discussion. A soluble starch does not imply complete solubility when the starch is made up in the customary concentration for use as an indicator but when the usual quantity of starch is added to the sample, the starch is so nearly soluble that if 1 ml is added to a 200-ml sample of water containing free iodine and the sample is then filtered through extra-heavy filter paper, the starch will pass through into the filtrate and substantially none will be

TABLE I—CHARACTERISTICS OF VARIOUS STARCHES

Starch	Temperature at which color forms with 0.015 ml O <sub>2</sub> per liter*	Iodo-starch color	Solubility rating**
a	110 F	Pink	5
b	109	Pink	5
c	80	Blue	6
d	77	Blue	6
e	77	Blue	2
f	75	Blue	4
g	75	Blue	6
h	73	Blue	1
i	73	Blue	3
j	65	Blue	1

a, Baker's wheat; b, Baker's corn; c, Baker's arrowroot; d, Pfanstiehl, potatoe, purified; e, Merck's, Soluble, according to Lintner; f, Merck's, C. P., Soluble; g, Baker's potatoe; h, Baker's C. P., Soluble; i, Baker's Soluble, purified; j, Pfanstiehl, Soluble, according to improved Lintner.

\* Iodine solution was added to the sample equivalent to 0.015 ml oxygen per liter at a temperature approximating 120 F and the samples were cooled in an ice bath to temperatures at which the iodo-starch color first formed.

\*\* Iodine, equivalent to 0.14 ml oxygen per liter was added to samples of which 50 ml was filtered. A solubility rating of 1 signifies only a trace of blue color remaining on the filter paper and the filtrate was a deep blue. A solubility rating of 6 signifies the blue color was retained on the filter paper and no blue color was found in the filtrate. The intermediate ratings between these two limits are designated by the numbers 2 to 5.

removed by the filter paper. Samples *e*, *f*, *h*, *i* and *j* do not have the same degree of solubility but are sufficiently soluble to be classed as soluble starches. Those having a rating of 5 or higher are classified as insoluble starches.

The operators A and B whose determinations are reported in Table II were both carefully trained technical men each of whom had previously made many hundreds of oxygen determinations by the Winkler test. The 200-ml samples were titrated with 0.01 N sodium thiosulphate solution in a white porcelain dish taking such precautions as a competent operator might well be expected to take in the field. Greater accuracy with the respective starches used should not be expected.

Table II shows that the tendency in the use of all of the insoluble starches is to read the oxygen too high, the reasons for this being that the insoluble starch particles floating in the water absorb iodine which requires an excess of sodium thiosulphate to remove the blue color unless special precautions are taken in the agitation of the sample and considerable time elapses between the addition of the last drops of sodium thiosulphate. It is also to be observed that the variations in determinations made by operators A and B (last column) are considerably greater for the insoluble than for the soluble starches. These variations are probably due to the difference in the effectiveness of the agitation during the time of adding the sodium thiosulphate. This illustrates a very practical objection to the use of the insoluble starches and the advantage of the soluble starches.

It is also shown by Table II that the tendency in the use of all the soluble starches is to indicate less oxygen than is actually present but this is of no particular importance because a correction factor must in any event be applied to all Winkler tests on account of the oxygen in the reagents.

Operators A and B did not differ in their determina-

tions by more than 0.002-ml oxygen per liter for 3 out of 5 soluble starches, nor by more than 0.008 ml for all 5 starches. Not too much significance should be placed on these small variations for these readings would not always be duplicated. We consider that a tolerance of 0.01-ml oxygen per liter is permissible in field tests. The determinations with all five soluble starches come within this tolerance for which reason any of these soluble starches may be used but either *h*, *i* or *f* are recommended. The starch that the Cochrane Corporation has for years supplied with its Winkler oxygen test kit is Baker's C. P. Soluble (*h* in table) with which starch operators A and B differed by only 0.002-ml oxygen per liter.

With insoluble starches operators A and B differed in their determinations by 0.017 to 0.081-ml oxygen per liter which difference is entirely too great for such accuracies as are required when testing deaerated boiler feedwater. Meisenburg and Fellows in their Progress Report on the "Accuracy of the Winkler Method for Dissolved Oxygen in Boiler Feedwater" presented at the midyear A.S.M.E. meeting at Chicago June 1933 concluded that the Root starches (Arrowroot-*c*) are preferable. Their conclusions were based largely on the greater sensitivity and better blue color of these starches at higher temperatures and did not deal with relative accuracies to be expected in the field.

It is also noticeable that, in general, insoluble starches are more sensitive at the higher temperatures than the soluble starches but this has no practical significance because the temperature at which the test is made can be controlled, and by applying proper corrective factors accurate results can be obtained with any of the soluble starches.

The starches used in the determinations referred to in this article, except only for Tables I and II, were either Baker's Arrowroot or Baker's C. P. Soluble starch. Baker's Arrowroot compares favorably with any of the insoluble starches but is subject to the disadvantages of all insoluble starches. The Baker's C. P. Soluble cannot be regarded as preferable to any of the other soluble starches. In fact Table II would suggest that starches *i* and *f* might be slightly more accurate than Baker's C. P. Soluble starch but the difference is inconsequential and comes well within the limits of accuracies that may be expected in making Winkler determinations even when taking all practical precautions that are emphasized in this report.

In order to obtain the extreme limit of sensitivity for Baker's C. P. Soluble and Baker's Arrowroot starches, titrations of various quantities of iodine solution were made at a temperature of 60 F employing greater refinements in making the test. Carefully standardized 0.002 N iodine and sodium thiosulphate solutions were used and sodium thiosulphate was added from a burette

TABLE II—ACCURACY OF STARCHES IN DETERMINING KNOWN QUANTITIES OF OXYGEN IN WATER AT 68 F

Starch	Solubility Rating	Iodine Added in Terms of Oxygen	Iodine Found by Operator A in Terms of Oxygen	Error of Operator A	Iodine Found by Operator B in Terms of Oxygen	Error of Operator B	Difference in Findings of A and B
h	1	0.279 ml/L	0.273 ml/L	-0.006 ml/L	0.275 ml/L	-0.004 ml/L	0.002 ml/L
j	1	0.279 ml/L	0.250 ml/L	-0.029 ml/L	0.242 ml/L	-0.037 ml/L	0.008 ml/L
e	2	0.279 ml/L	0.273 ml/L	-0.006 ml/L	0.267 ml/L	-0.012 ml/L	0.006 ml/L
i	3	0.279 ml/L	0.273 ml/L	-0.006 ml/L	0.273 ml/L	-0.006 ml/L	0.000 ml/L
f	4	0.279 ml/L	0.278 ml/L	-0.001 ml/L	0.278 ml/L	-0.001 ml/L	0.000 ml/L
a	5	0.279 ml/L	0.325 ml/L	+0.046 ml/L	0.306 ml/L	+0.027 ml/L	0.019 ml/L
b	5	0.279 ml/L	0.347 ml/L	+0.068 ml/L	0.325 ml/L	+0.046 ml/L	0.022 ml/L
c	6	0.279 ml/L	0.395 ml/L	+0.116 ml/L	0.314 ml/L	+0.035 ml/L	0.081 ml/L
d	6	0.279 ml/L	0.370 ml/L	+0.091 ml/L	0.387 ml/L	+0.108 ml/L	0.017 ml/L
g	6	0.279 ml/L	0.378 ml/L	+0.099 ml/L	0.336 ml/L	+0.057 ml/L	0.042 ml/L



with a specially bevelled and waxed tip to give 50 drops per ml as compared with the 20 drops for the ordinary burette tip. As the endpoint was approached each additional drop of sodium thiosulphate solution was followed by thorough agitation for considerable time to insure contact of sodium thiosulphate with each starch particle. All of the final endpoints were checked by pouring a portion of the sample into a Nessler tube and comparing this with a standard tube containing an excess of sodium thiosulphate solution. The samples were added to the Nessler tube while they still showed a very faint blue, following which an additional drop or two of thiosulphate solution was added as required to completely remove the blue color. The results of these tests are shown in Fig. 1.

The graph shows that the sensitivity of Baker's Arrowroot starch is greater than that of Baker's C. P. Soluble by 0.002-ml oxygen per liter and furthermore that the Baker's Arrowroot starch at a temperature of 60 F will indicate all of the oxygen that is in the samples whereas the endpoint with Baker's C. P. Soluble starch is reached when the sample still contains iodine equivalent to 0.002 ml per liter. This greater sensitivity of the Arrowroot starch might represent a theoretical advantage of the latter but as this difference in sensitivity is beyond the limits of accuracy that can be obtained in field tests, it is of no practical significance. On the other hand, as shown by Tables I and II, the errors in making the titration with Arrowroot starch make its use impractical in the field.

The effect of temperature on the iodo-starch reaction is well illustrated by Fig. 2. This graph shows that with Baker's C. P. Soluble starch a quantity of iodine equivalent to 0.07-ml oxygen per liter is required to give a blue color at 100 F, whereas at 140 F, 0.44 ml of oxygen per liter are required. However, a blue color once formed at 100 F or a lower temperature with 0.07-ml oxygen per liter, will retain that blue color until the temperature is raised as high as 140 F.

With Baker's Arrowroot starch a quantity of iodine equivalent to 0.04-ml oxygen per liter gives a blue color at 100 F, whereas 0.38-ml oxygen is required at a temperature of 140 F. This illustrates why the Winkler test may indicate zero oxygen if the sample has not been properly cooled even though the water may contain considerable oxygen. The curves become quite flat at a temperature of 70 F.

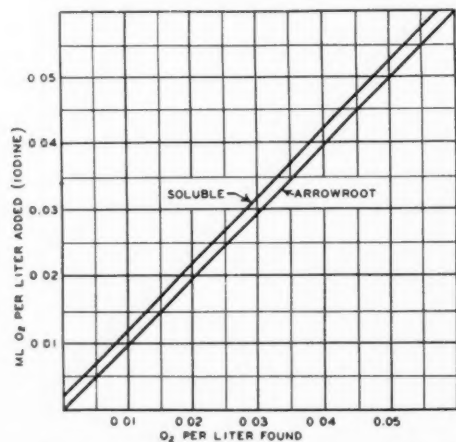


Fig. 1—End-point comparison between Baker's C. P. Soluble starch and Baker's Arrowroot starch at 60 F. (Not practical for field use)

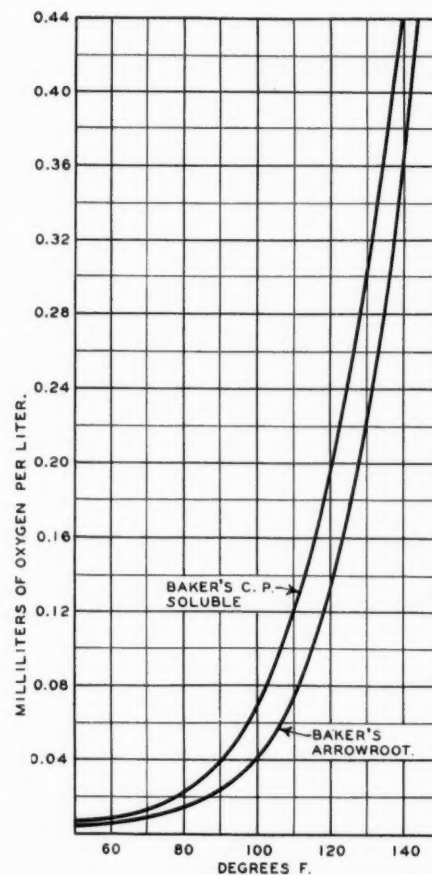


Fig. 2—Temperature at which blue color forms with various amounts of oxygen

#### Oxygen in Reagents

At the beginning of this work which extended over more than a year an attempt was made to secure completely deaerated water by continued boiling and careful sampling. It was found that no amount of deaeration would indicate zero oxygen when the Winkler test was properly made at a temperature of 60 F. This was attributed to the oxygen that was in the reagents, manganous chloride and sodium hydroxide-potassium iodide solutions. One milliliter of each of these is added to a 280-ml sample as the first steps in the Winkler method.

To check this theory and to determine the quantity of oxygen thus introduced various quantities of these reagents were added to the same size samples from which it was found that when preparing these solutions with water from a laboratory still, the addition 1-ml manganous chloride and 1-ml sodium hydroxide-potassium iodide solutions to a 280-ml sample of water, introduces the equivalent of 0.015-ml oxygen per liter. This requires that when determining the oxygen in deaerated boiler feedwater by the Winkler method a correction factor must be applied for the oxygen in the reagents depending upon the temperature.

Fig. 3 shows the values that must be deducted from the oxygen determinations for temperatures ranging from 50 to 85 F when using Baker's C. P. Soluble starch and when adding 1 ml each of manganous chloride and sodium hydroxide-potassium iodide solutions to a 280 ml sample. As indicated by Fig. 3 if the titration with sodium thiosulphate is completed at 70 F the value to be deducted is approximately 0.01-ml oxygen per liter, whereas if the test were made at 85 F this value is zero,



i.e., no correction would need to be applied. At 60 F the value to be deducted is 0.013-ml oxygen per liter. If Arrowroot starch is used and the test is made with utmost care the correction factor is 0.015 ml at 60 F; see Fig. 2 and description of tests used in plotting Fig. 2.

Unless special precautions are taken interferences of two classes may be present:

1. Substances having oxidizing properties as nitrites, ferric salts, red lead, etc., which will cause the oxygen determinations by the Winkler method to be too high.
2. Substances having reducing properties as sulphides, sulphites, etc., which will cause oxygen determinations by the Winkler method to be too low.

If nitrites are present the Rideal-Stewart modification may be used when testing undeaerated water. It is, however, impossible to apply the Rideal-Stewart method with such accuracy as to make it useful in determining oxygen in such small quantities as are found in deaerated boiler feedwater.

Fortunately, nitrites are not often present in feed-water to an extent to cause interference but if proved to be present no method is yet available for determining the oxygen to such a degree of accuracy as required for boiler feedwater.

Ferric oxide, or iron rust, from pipes is occasionally present and gives too high oxygen readings in which event the iron oxide can be removed by carefully filtering the sample to be tested through a fine sand filter. In this event care must be taken to wash out all oxygen from the filter. This washing must be done with the filter between the cooling coil and the sample bottle to obtain the benefit of the solvent action of the cold water in removing the air. The need for such filtration fortunately is rarely required.

Only a trace of red lead frequently used in making joints will give too high oxygen readings. The presence of red lead must be avoided.

A common source of sulphides is rubber tubing used in making connections to the sample bottle. To avoid such contamination sulphur-free tubing should be used and the length of rubber tubing should be as short as possible. Passage of deaerated water through a new four-foot length of rubber tubing has caused the Winkler method to show zero oxygen when the water was known to have as much as 0.06-ml oxygen per liter. It required passing water through such tubing for several days to wash out the sulphides to eliminate interference.

A rubber stopper is frequently used on the sodium hydroxide-potassium iodide-reagent bottle because of the solvent action of caustic soda on glass causing glass stoppers to stick. The use of rubber stoppers on these reagent bottles has frequently been found to add sufficient sulphides to the sodium hydroxide-potassium-iodide reagents to indicate zero oxygen in the water when as

much as 0.10-ml oxygen was present. This contamination should be avoided by the use of glass stoppers coated with paraffine to prevent sticking. To insure the absence of interfering substances in both the water to be tested and the reagents, the following tests should be made:

#### A—Interference Giving High Oxygen Results

Rinse out and fill the sampling bottle with water. Add 1 ml of sodium-hydroxide potassium-iodide solution. This solution must be added first, and acidified before the manganous chloride is added, otherwise a precipitate will be formed and the oxygen of the water will enter into reaction. Add 5 ml of hydrochloric acid, replace the stopper in the bottle and turn the bottle over and over in order to thoroughly mix the solutions. Rinse off the neck of the bottle and add 1 ml of manganous chloride solution, replace the stopper and turn bottle over and over to mix. Measure out 200 ml of this sample and cool to 60 F. Pour into test dish, add starch solution and stir thoroughly.

If the sample turns blue this shows the presence of substances having oxidizing properties which will give high oxygen results in either the water or reagents as nitrites, ferric oxide, lead oxide, etc., and the source of contamination must be found. If the sample does not turn blue no such interfering substances are present and you may proceed in testing for—

#### B—Interference Giving Low Oxygen Results

Add 1 drop of 0.01 N iodine solution to the sample and stir thoroughly. If the sample turns blue neither the reagents nor sample of water contains any reducing agents to give too low oxygen results. If the sample does not turn blue with 1 drop of 0.01 N iodide solution, additional iodine may be added to determine the extent of interfering substances present and the source of these should be investigated and corrected.

If no interference is shown to be present by either of these tests no interfering substances are present to prevent accuracy within 0.01-ml oxygen per liter.

#### Method of Sampling

Care must be exercised in withdrawing samples to avoid exposure to the air and to avoid boiling or "flashing." The samples should be drawn from some point in the outlet piping close to the equipment where the pressure of water in the line is above atmospheric. Copper tubing should be used to convey the sample to a copper cooling coil. If it is necessary to use rubber tubing, the connections should be as short as possible and sulphur-free rubber should be used.

In order to prevent "flashing" with a resultant loss of oxygen, all valves ahead of the cooling coil should be full open while samples are being withdrawn, and the flow should be controlled by throttling the valve or screw clamp on the discharge side of the coil.

The rate of flow should be controlled so that the temperature of the water leaving the cooling coil does not exceed 85 F. If it is impossible to obtain this temperature, this sample must be cooled with ice before the final titration with sodium thiosulphate is made.

Several types of sampling bottles have been used, but for simplicity of handling with reliable results we recommend the glass stoppered sampling bottle shown with cooling coil as in Fig. 4. The only precaution to

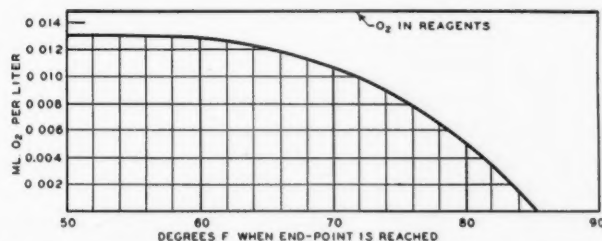


Fig. 3—O<sub>2</sub> per liter to subtract from total O<sub>2</sub> to correct for the O<sub>2</sub> introduced with the reagents when using Baker's C. P. Soluble starch

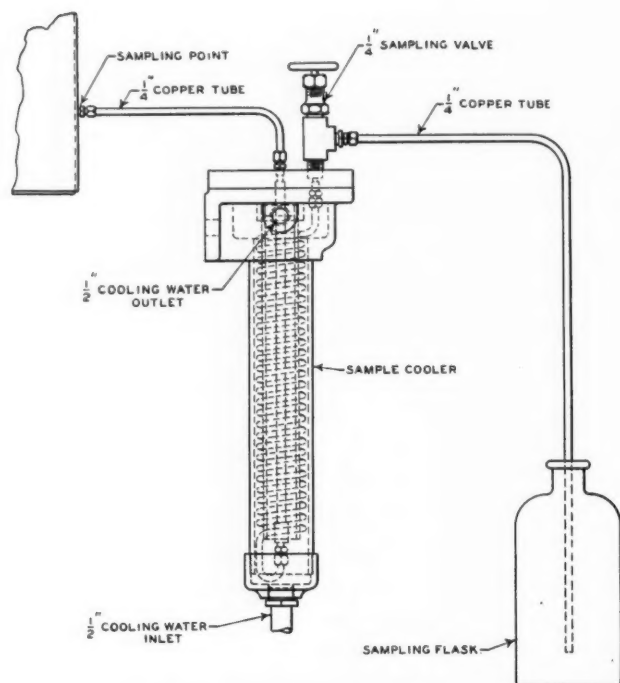


Fig. 4—Type of sampling bottle recommended

take with this type of bottle is to hold it on an angle when inserting the glass stopper so that no air bubble will be trapped under the stopper.

The water entering the sampling bottle should be carried to the bottom of the bottle by either a straight piece of copper tubing after the throttling valve when an all copper connection is used, or a  $\frac{1}{4}$ -in. diameter piece of glass tubing after the screw clamp when rubber tubing is used. The water should be allowed to overflow until the volume of the bottle has been displaced at least six times. After the sampling bottle is properly filled the tube admitting the water is removed slowly, and the glass stopper is quickly inserted to prevent the absorption of oxygen.

#### Solutions for the Winkler Test

1. Manganous Chloride. Forty grams of  $\text{MnCl}_2 \cdot 4\text{H}_2\text{O}$  dissolved in water and diluted to 100 ml. Filter if solution contains suspended matter. Use 1 ml to a 280-ml sampling bottle.
2. Sodium Hydroxide-Potassium Iodide. Forty two grams of sodium hydroxide dissolved in water; add 10 grams of potassium iodide and dilute to 100 ml. Use 1 ml to a 280-ml sampling bottle.
3. Concentrated Hydrochloric Acid. Use 5 ml to a 280-ml sampling bottle.
4. Starch. Two grams of Baker's C. P. Soluble starch pasted with cold water, added to 100 ml of boiling water and boiled for a very short time. Use 1 ml to a 200-ml sample of water in the test dish.
5. 0.01 N Sodium Thiosulphate. One ml to 200-ml sample is equivalent to 0.28 ml of oxygen per liter.
6. 0.01 N Iodine Solutions.

#### Adding the Reagents

Add 1 ml of manganous chloride solution with a pipette, inserting the tip of the pipette below the surface of the water in the sampling bottle. Add 1 ml of sodium-hydroxide potassium-iodide solution in the same manner.

Be sure to keep the pipettes separate and do not interchange them from one reagent bottle to the other unless they are thoroughly washed out. The pipettes should always be washed out with fresh water before putting them away. Replace the stopper in the bottle and turn the bottle over and over until the precipitate has been thoroughly distributed throughout the sample. Allow the precipitate to settle to the bottom of the sampling bottle, which takes approximately two minutes.

Add 5 ml of hydrochloric acid in the same manner as described for the other solutions. Rubber tubing should be used with the pipette to avoid any possibility of drawing up acid into the mouth. Replace the stopper in the bottle and turn the bottle over and over until the acid has dissolved all of the precipitate and the sample is thoroughly mixed.

The sample is now "fixed" and it may be exposed to the air without affecting the results. It should, however, be tested as soon as possible and should not be exposed to direct sunlight.

#### Titrating the Sample

Rinse the burette out several times with sodium thiosulphate solution and fill, being sure to remove the air from the burette tip.

Rinse out the volumetric flask with a small portion of the sample and fill the flask up to the 200-ml etched line on the neck. If the temperature of the sample is higher than 85 F, cool it by placing the flask in ice water.

Pour the cool 200-ml sample into a clean white test dish and add 1 ml of starch solution.

Stir the sample and if no color is obtained at 85 F the water has less than 0.03-ml oxygen per liter, which may be considered zero.

If a blue color is obtained at 85 F, the sample should be titrated with sodium thiosulphate solution, adding drop by drop with constant stirring, until the blue color disappears. Multiply milliliters of sodium thiosulphate by 0.28 which will give the milliliters oxygen per liter in the sample if tested at 85 F. If the sample is tested at a temperature below 85 F deduct from the oxygen found the correction for oxygen in the reagents as given by the curve Fig. 3. The temperature of the sample should always be taken when the endpoint is reached, and this temperature should be applied to the curve, Fig. 3.

#### Conclusions

The Winkler method, with its well-known modifications, is very satisfactory for determining the oxygen in surface waters for which an error of 0.1 to 0.2-ml oxygen per liter is permissible. This is not sufficiently accurate when determining oxygen in boiler feedwater for which deaerating heaters are generally guaranteed to reduce the oxygen to 0.03 ml or less. For these low quantities the test should be accurate within 0.01-ml oxygen per liter, which degree of accuracy can be obtained in field determinations with the Winkler method if a proper grade of soluble starch is used, the sample is tested at a temperature of 85 F or less, a correction is made for oxygen in the reagents, all interfering substances are avoided and proper precautions are taken in drawing the samples and in making the tests as herein described.



## New Dust Collector Employs Double Eddy Currents

A NEW system of flue dust collection, invented by Hermannus Van Tongeren of Holland, has lately been attracting wide attention abroad. It is based primarily on utilization of the double-eddy currents within the main cyclone which surrounds the stack.

The usual method is to force dust-laden gas into a curved channel or volute path in which the dust particles are separated by centrifugal force and deposited in suitably arranged collectors or sheared off from the gas current by shearing plates. The branch current, containing most of the dust in a small quantity of gas, is then freed of the dust by cyclones or dust channels.

Fig. 1 illustrates the double-eddy effect as made use of in the Van Tongeren collector. Assuming the main current to be flowing perpendicular to the plane of the paper, the arrows at the right indicate the two halves of the double-eddy current which is always present. The dust particles are carried along to the periphery by the double-eddy currents, which have a velocity much greater than

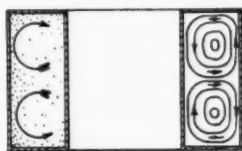


Fig. 1—Illustrating double-eddy effect

that of the main current, and cause the loading of the gases to be much higher at the edges of the casing, particularly near the center.

Fig. 2 shows how the dust is sheared off by the U-shaped slot S. The gas outlet does not extend over the whole height of the casing but leaves covered the parts C and D at the top and bottom, respectively, where the gas cannot escape to the chimney. This is important because the double-eddy current carries dust to these sections which would otherwise escape to the stack.

The collector at the center is provided with vanes in the opening which are directed opposite to the main current. These are pivoted and the angle can be varied to suit the load. At peak load the vanes are fully open to reduce resistance. At lower loads the vanes are partly closed and their separating action increases. This neutralizes the decrease in dust-collecting efficiency due to the lower velocity of the main current. A relatively flat efficiency curve is claimed.

The cylindrical part of the cyclone is directly connected with the hopper and a dust collecting gutter, having several shearing edges, is provided. The relatively small amount of gas that carries the dust to the hopper is returned through the central tube.

The arrangement is said to be especially compact.

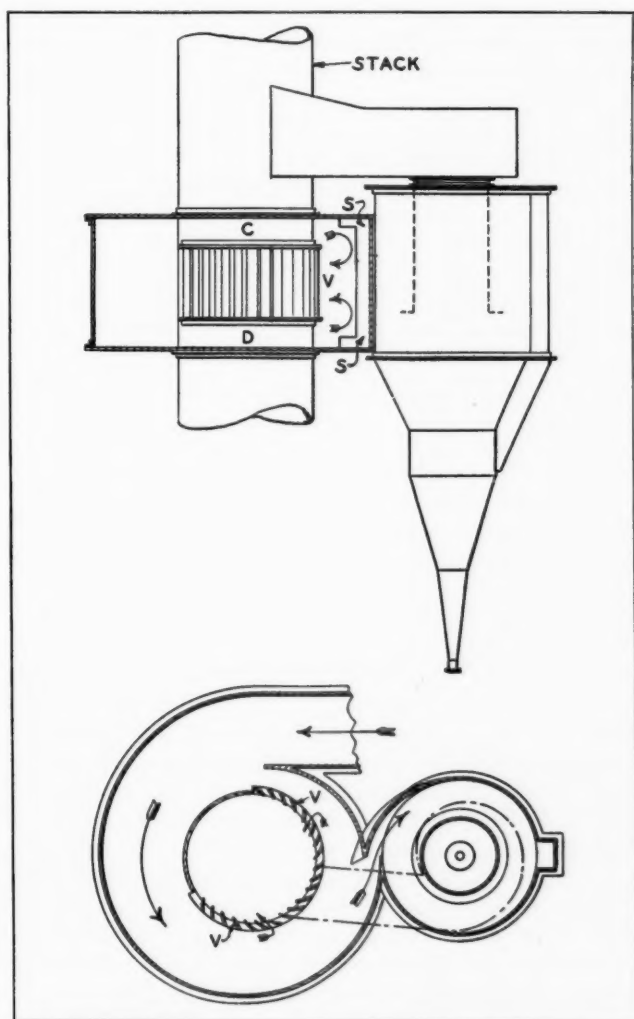


Fig. 2—Plan and elevation of collector

## A. C. Willard Becomes President of University of Illinois

At a meeting of the Board of Trustees on March 13, Arthur Cutts Willard was selected as President of the University of Illinois and will take office July 1. The action of the Board was unanimous and President Willard succeeds Harry Woodburn Chase, who became Chancellor of New York University last year. President Willard has been acting Dean of the School of Engineering for some time and as head of the Department of Heating and Ventilation he received world-wide recognition for his research work. He is an internationally known authority and an outstanding engineer, author, educator and research investigator.

President Willard was born in Washington, D. C., and after receiving his preparatory education in the public schools of the District of Columbia, he attended Massachusetts Institute of Technology and was graduated in 1904. He commenced his teaching career immediately in California and in 1906 became assistant Professor of Mechanical Engineering at George Washington University. From 1909 to 1913, he served the Government as Sanitary and Heating Engineer, in the office of the Chief Quartermaster of the Army. Since 1913, President Willard has been a member of the Faculty of the University of Illinois, first as Assistant Professor of Heating and Ventilation, and then in charge of the Department of Mechanical Engineering. In 1928 he was president of the American Society of Heating and Ventilating Engineers.

Samuel M. Green, consulting engineer and designer of many industrial and building power plants in New England, died at his home in Springfield, Mass., on March 22. He was seventy years old.



# Air Leakage in Steam Generating Units

By W. S. PATTERSON, Combustion Engineering Company, Inc.

## PART II MEASUREMENT and CALCULATION

### *Difficulty of Measurement of Air Infiltration*

There is no way of measuring directly, the quantity of infiltration air which is continually leaking into the various parts of a steam-generating unit. It can, however, be indirectly calculated by determining the measurable effect it has on something else. For instance, if air at known room temperature is leaking at an unknown rate into a conduit containing a flue-gas stream at higher temperature it is obvious that the infiltration affects (1) temperature, (2) weight and (3) composition of the gases passing some other point farther along. By affecting weight it may also cause a change in (4) the frictional resistance or pressure drop per unit of length of duct. And if the infiltration or leakage air enters the system through the furnace walls where it will, at least to some extent, take part in combustion of the fuel then it will have a measurable effect on (5) the quantity of air passing through the air preheater or supplied under control to the furnace. There are, therefore, at least five indirect methods of measuring infiltration, but all are not applicable to every problem.

Before discussing these various methods in detail, a few words regarding the accuracy that can be expected will be in order. It should be kept in mind that in all these measurements we are dealing with a huge flowing stream of gas, commonly more than 300 tons per hour, passing along a tortuous path, first upward and downward over variously arranged boiler tubes and baffles, then upward or downward over economizer tubes and then likewise over the air-heater surface. Since the gases will often carry along considerable ash or soot, provision is sometimes made for a sudden reversal of direction between each piece of apparatus and hoppers arranged for removal of some of the soot collected by this means. These hoppers often cause uneven gas distribution over the following heat recovery apparatus which, in turn, may cause, uneven temperature farther along. Also, since each piece of apparatus is generally independently supported, expansion joints must be provided in the connecting duct work. If these leak air, then the composition of the gases flowing along the walls will be richer in oxygen and leaner in carbon dioxide than the gases nearer the center of the duct. The writer desires to emphasize that, regardless of where along the gas path the measurements are taken, there will always be considerable variation in temperature, velocity and gas composition as one traverses the cross-section of the duct or boiler pass, as the case may be.

In the preceding article of this series, which appeared in the February issue of *Combustion*, the factors affecting the occurrence and magnitude of air infiltration and leakage were discussed in detail. In this article the methods of measurement together with their attendant difficulties and sources of error are studied. It is shown that infiltration measurements are not simple and that the largest items are the most difficult to measure.

Accurate determination of the arithmetic average temperature of the gases at a certain cross-section, having considerable temperature gradient from front to back and from side to side, will therefore be a laborious task. If readings are obtained, one by one, for each square foot of cross-section, or some larger unit of area, considerable time may be consumed, and, to make the results of any value, check readings should be taken at several fixed stations simultaneous with the readings taken at new traverse stations.

Consider a particular problem, that of determining the heat absorbed from flue gases passing through an air heater, which is part of the problem of determining furnace infiltration to be discussed later. Let Fig. 1 represent the arrangement of the air heater with a horizontal gas-inlet duct. Assume also that the inlet and outlet air connections are located on the same side as shown. It is quite probable that a greater gas weight, per square foot of cross-section of the gas passage, will travel through the tubes or lanes at the rear of the heater than at the front. This uneven distribution will vary with the velocity of impact of the gases against the back plate of the inlet gas duct. But the air distribution will also be uneven since it will prefer to travel the shorter inside path of least resistance. Thus, most of the gas will pass through the rear half and most of the air through the front half of the heater causing an appreciable gradient in the outlet gas temperature from front to back of heater as shown by Fig. 1. Obviously, in order to determine the average temperature of the gases leaving the heater, with which to calculate the sensible heat leaving the unit, an average temperature weighted against both linear velocity and density must be used. It cannot be weighted against linear velocity alone since volumes at different temperatures are not additive.

The calculations involved in this averaging process are shown in Table I for the conditions as given in Fig. 1.

TABLE I—CALCULATION OF AVERAGE TEMPERATURE FOR FIG. 1

1	2	3	4	5	6
Traverse Point	Measured Temperature, F	Measured Linear Velocity, Ft per Sec	Density Corrected for Temperature Lb per Cu Ft	Mass Velocity Lb per Sq Ft per Sec Col. 3 X 4	Product of Col. 2 X 3 X 4
a	520	50	0.0405	2.02	1052
b	475	45	0.0425	1.91	908
c	450	40	0.0436	1.74	785
d	350	33	0.0490	1.62	566
Sum	1795	168	0.1756	7.29	3311
Arith. avg	449	42	0.0439	1.82	

Then the weighted average temperature is  $3311/7.29 = 454$  F.

The densities of the gas listed in Column 4 of the table are corrected for temperature and taken for dry air for the sake of simplicity. This also assumes constant mean specific heat and uniform composition of the gases, which hardly ever exist in practice, but the error thus introduced for this particular calculation is very small. It will be noted, however, that the difference between a single haphazard temperature measurement and the weighted average temperature might be quite appreciable. It is often enough to completely upset the accuracy of air infiltration measurements by indirect methods, enumerated above, which will now be discussed.

#### Various Methods of Measuring Air Infiltration

The method of calculating the rate of air infiltration by measuring its effect on the average temperature of the gas stream is, in its simplest form, only applicable to sections of a steam-generating unit in which the temperature of the gas would otherwise remain constant, as in a section of well-insulated breeching from which the radiation loss might be negligible in comparison with the effect of infiltration or in the primary air line to a pulverizer where tempering air is used. This method

enables the percentage increase in gas weight between two sections to be calculated without determining the actual gas-flow rate at either section. The equation for the calculation may be written:

$$[W_1 \times C_1 (t_1 - t_0)] + [W_3 \times C_3 (t_3 - t_0)] = [W_2 \times C_2 (t_2 - t_0)] \quad (1)$$

in which the subscripts 1, 2 and 3 refer respectively to the first section passed, the second section passed and the infiltration air.  $W_1$ , etc. is the weight rate of flow per unit of time or the weight per pound of fuel;  $C_1$ , etc. the mean specific heat at constant pressure between the limits of temperature indicated in parenthesis;  $t_1$ , etc. the average fluid temperature, and  $t_0$  an arbitrarily assumed datum of temperature. By taking the temperature of the infiltration air as the datum and substituting  $t_3 = t_0$  in equation (1) the second term will disappear completely,  $W_1/W_2$  may be calculated by measuring  $t_1$  and  $t_2$ , and the percentage increase in weight readily determined. The equation so modified is:

$$W_1 \times C_1 (t_1 - t_3) = W_2 \times C_2 (t_2 - t_3) \quad (2)$$

The above equation could not, however, be used to determine the amount or percentage of infiltration between inlet and outlet of an economizer because of the gas temperature reduction due to heat absorbed by the water,  $H_w$ , and radiation loss,  $H_r$ . Equation (2) modified to suit an economizer would be:

$$[W_1 \times C_1 (t_1 - t_3)] - [H_w + H_r] = [W_2 \times C_2 (t_2 - t_3)] \quad (3)$$

in which the subscripts 1 and 2 refer, respectively, to the gas inlet and outlet of the economizer;  $H_w$  and  $H_r$  are heat losses from the gas stream to water and by radiation respectively, in consistent units. The other nomenclature is as in equation (1). In a large well-insulated economizer the value of  $H_r$  would be negligible when added to  $H_w$ . It is obvious from this equation, however, that neither the percentage increase in gas weight due to infiltration nor the quantity of infiltration represented by  $(W_2 - W_1)$  can be determined without first knowing either  $W_2$  or  $W_1$ .

The method of calculating the quantity of air infiltration by measuring the increase in mass flow between two sections of a steam-generating unit is the one which is generally used for determining leakage into boiler settings, economizers and air preheaters. The methods of measurement of mass flow in pounds per hour past any cross-section are all indirect methods; that is, the entire quantity of flowing gas cannot be conveniently passed through a gas meter or into a gasometer as is done in some industries. The most direct of the indirect methods is to determine average velocity, area of cross-section and average density. The product of these three gives the mass flow from the equation:

$$W = A \times V \times d \quad (4)$$

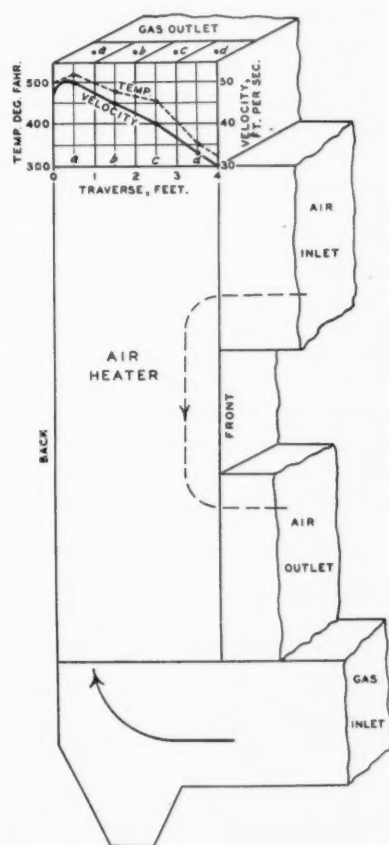


Fig. 1—Arrangement of air heater showing how design of gas inlet duct and heater may affect outlet gas temperature and velocity, thus complicating their measurement



in which, if  $A$  is the net passage area in square feet,  $V$  the average linear velocity in feet per hour, and  $d$  the average density in pounds per cubic foot, then  $W =$  the mass flow in pounds per hour. The product  $Vd$  is the mass velocity in pounds per square foot per hour.

Procedure for measuring average linear velocity is not standard, but the instrument most adaptable to the particular problem of measuring flue-gas velocity is the pitot tube. This instrument has various forms which give slightly different results and have slightly different characteristics. Some types are designed especially for low velocities. For a detailed description of their design and use the reader is referred to other literature on the subject<sup>1,2</sup>. There are several methods of obtaining average velocity in rectangular ducts. Perhaps the easiest is to visualize the cross-sectional area divided into squares of equal area and to proceed by measuring the velocity at the center of each square. Then if the measured velocity were the true average velocity for each and every square, the arithmetic average of the individual measurements would be the true average velocity for the total passage area. The accuracy of this method depends largely on the size of the imaginary divisions of area for which the center velocities are measured. Even in a smooth conduit with extremely low velocity and so-called viscous or streamline flow the velocity decreases sharply near the walls so that any method which professes accuracy must include velocity measurements near the walls. Since this would greatly increase the number of measurements for the equal area method described above, other methods have been devised involving perhaps less time in making measurements but more time in calculating the results, with the distinct advantage, however, of greater accuracy.<sup>2</sup>

The density factor,  $d$ , in equation (4) must be the weighted average if there is considerable variation in gas composition or temperature or both. Otherwise, considerable error may be introduced since the density of the flue gases will depend only on the chemical composition and temperature, pressure being practically constant. The simplest method of using equation (4) where all three factors are variable with respect to position in the cross-section, is to measure velocity, gas composition and temperature at the center of as many squares of equal area as the required accuracy may justify. From this the various values of  $d$  and  $(V \times d)$  may be calculated and the arithmetic average of the  $(V \times d)$  products then multiplied by the area,  $A$ . By repeating this procedure

<sup>1</sup> Fluid Meters Report, Part I, A.S.M.E.

<sup>2</sup> Experimental Engineering, Vol. I, Eng. Inst., Diederichs & Andrae.

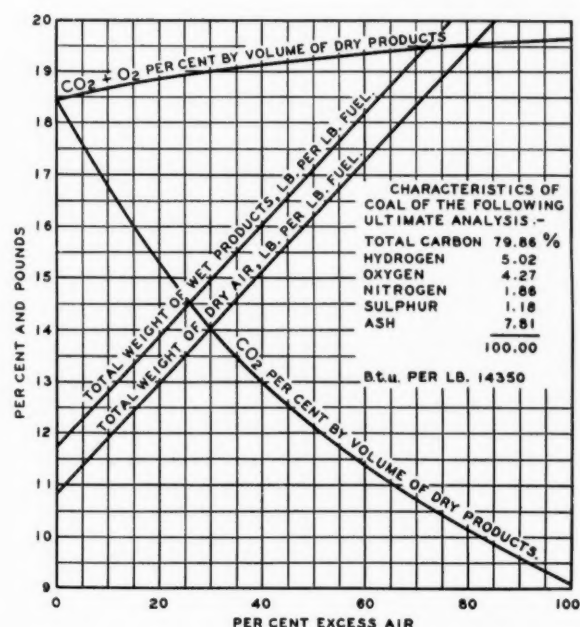


Fig. 2—Characteristics of a particular bituminous coal showing air weight required, resulting gas weight and gas analysis after complete combustion

at some other cross-section of the flue-gas path, the quantity of air infiltration occurring between can be quite accurately determined.

Another of the indirect methods of determining the amount of infiltration by measuring the difference in mass flow between two sections of the flue-gas path involves the use of the chemical formulas for combustion of fuels. The accuracy of this method depends on the accuracy of determination of (1) the ultimate analysis of the fuel, (2) the weight of fuel burned per unit of time and (3) the chemical composition of the flue gases at the two sections of the flue-gas path under consideration.

Consider one pound of any fuel as delivered to a furnace. It will be made up of ash, water and the chemical elements carbon, hydrogen, sulphur, nitrogen and oxygen. In some fuels, such as oil and natural gas, the carbon may be entirely in hydro-carbon form and in others, such as blast furnace gas, much of it may be partially or wholly oxidized in the form of CO or CO<sub>2</sub>. However, regardless of the fuel, if its combustible and other constituents are known, the weight of air required to burn it can be calculated, and no matter how much excess air is assumed to be necessary the chemical composition of the resulting combustion products or flue gases can be

TABLE II—SAMPLE OF INFILTRATION CALCULATIONS FOR 100,000-LB PER HR, PULVERIZED-FUEL FIRED UNIT

General Operating Conditions					
200 F feed, 200 F superheat, 450 lb gage line pressure, 85 per cent overall efficiency, 9570 lb per hr of 14350 Btu coal as fired, carbon loss negligible, no CO in gas					
Measurements and Calculations for Air Infiltration					
Measurement at	Furnace Outlet	Boiler Outlet	Economizer Outlet	Air Heater Outlet	Induced Fan Inlet
Measured avg CO <sub>2</sub> by Orsat	16	15.0	14.5	14.0	13.5
Measured avg O <sub>2</sub> by Orsat	2.7	3.9	4.5	5.0	5.6
Per cent excess air (from Fig. 2)	15	22	26	30	35
Flue gas per pound coal (from Fig. 2)	13.35	14.10	14.52	14.95	15.50
Total air per pound coal (from Fig. 2)	12.43	13.18	13.60	14.03	14.58
Pound flue gas per hour	127700	134900	138900	143000	148260
Pound total air per hour	118900	126100	130100	134200	139460
*Furnace					
Infiltration into		Boiler	Economizer	Air Heater	Breeching
Infiltration, pound per pound coal		0.75	0.42	0.43	0.55
Infiltration, pound per hour		7200	4000	4100	5260
Infiltration, per cent of theoretical air		7	4	4	5
Infiltration, per cent of air at boiler outlet		5.7	3.2	3.3	4.2

Primary air required by pulverizer, assume 1.5 lb per lb of coal at not over 300 F. Temperature of primary air available from air heater, assume 450 F. Then from equation (1) cold tempering air required at 70 F = 0.60 lb; used with 0.90 lb at 450 F. Then pulverizer tempering air = 5.5 per cent of theoretical air = 4.5 per cent of air at boiler outlet.

\* For calculation of furnace infiltration see the text.



predicted with accuracy. Conversely, therefore, with the fuel analysis and solid carbon loss known, if the composition of the flue gases can be accurately measured, the amount of air per pound of fuel supplied up to the point of flue gas analysis can be accurately calculated. And, going one step further, if the weight of fuel burned per hour is known the gas weight in pounds per hour passing the section in question may be determined, which should be the same as  $W$  in equation (4).

The most accurate method of calculating the combustion products for any fuel is to calculate, by either the law of combining weights or by Avogadro's law, the required amount of oxygen to completely burn each of the combustible elements or compounds determined by ultimate analysis of the fuel.<sup>3</sup> Since the dry fuel will probably contain oxygen by analysis, in addition to that reported in combination with hydrogen in the form of water, the oxygen so calculated will not be the oxygen required to be supplied by the air. Subtraction of the

<sup>3</sup> For details see Haslam & Russell, *Fuels and Their Combustion*.

oxygen reported in the analysis gives the oxygen to be supplied by the air, and multiplying the result by the ratio of nitrogen to oxygen in the air, gives the amount of nitrogen accompanying the oxygen. The nitrogen in the fuel added to that from the air gives the total nitrogen in the products. Obviously, the products of combustion per pound of fuel can now be determined by addition and the result expressed either in pounds or mols, depending on the system of calculation used. The percent by volume of the various constituents may also be calculated. This is generally done on the dry basis and the  $\text{SO}_2$  added to the  $\text{CO}_2$  and considered as  $\text{CO}_2$  because the Orsat apparatus generally used for flue-gas analysis gives the results on this basis. By adding more and more air as dilution, the total products may be calculated and plotted graphically against variation in  $\text{CO}_2$  or excess air as in Fig. 2. Then by analysis of the flue gases in any part of the steam-generating unit, beyond where combustion is determined to be complete, the total weight of products per pound of fuel may be determined accurately. The accuracy depends, of course, on the method of sampling and whether or not allowance is made for variation in gas velocity across the passage. Finally, from the measured fuel weight fired, the mass flow may be determined in pounds per hour.

By making the assumption first, that both nitrogen and sulphur are present in negligible quantities, second, that combustion is complete with the exception of known solid carbon loss and very small amounts of CO and, third, that the hydrogen available for combustion is the hydrogen reported in the analysis corrected for the oxygen content of the fuel, the following equation may be developed for solid and liquid fuels:

$$W_d = C_b \times \frac{11\text{CO}_2 + 8\text{O}_2 + 7(\text{CO} + \text{N}_2)}{3(\text{CO}_2 + \text{CO})} \quad (5)$$

in which  $W_d$  is the weight of dry flue gas per pound of fuel;  $C_b$  the pounds of carbon burned per pound of fuel fired; and  $\text{CO}_2$ ,  $\text{O}_2$ ,  $\text{CO}$  and  $\text{N}_2$  are percentages by volume of these constituents in the dry gas as determined by analysis. Therefore, from the flue gas analysis the weight of dry gas per pound of fuel may be readily calculated and, adding the moisture from the fuel, moisture due to combustion of hydrogen and moisture from humidity of air, the total flue gas per pound of fuel will result.

By making the additional assumptions in connection with equation (5), first,  $(\text{CO}_2 + \text{O}_2 + \text{CO} + \text{N}_2)$  in the numerator = 100, second, CO in the denominator = 0 and, third,  $\text{CO}_2 + \text{O}_2$  in the numerator = 20, all of which are within reason and introduce only small error for coal, then equation (6) becomes:

$$W_d = C_b \left[ \frac{240}{\text{CO}_2} + 1 \right] \quad (\text{for coal only}) \quad (6)$$

where the nomenclature is the same as for equation (5). Either equation (5), equation (6) or the more accurate method involving all the individual chemical elements of the fuel may be used to calculate the mass flow of flue gases at a given point in the system. The A.S.M.E. Power Test Code allows the use of equation (5). The importance of obtaining an average sample of the flue gases cannot be over-emphasized and the reader is again referred to other literature for a detailed discussion of the procedure.

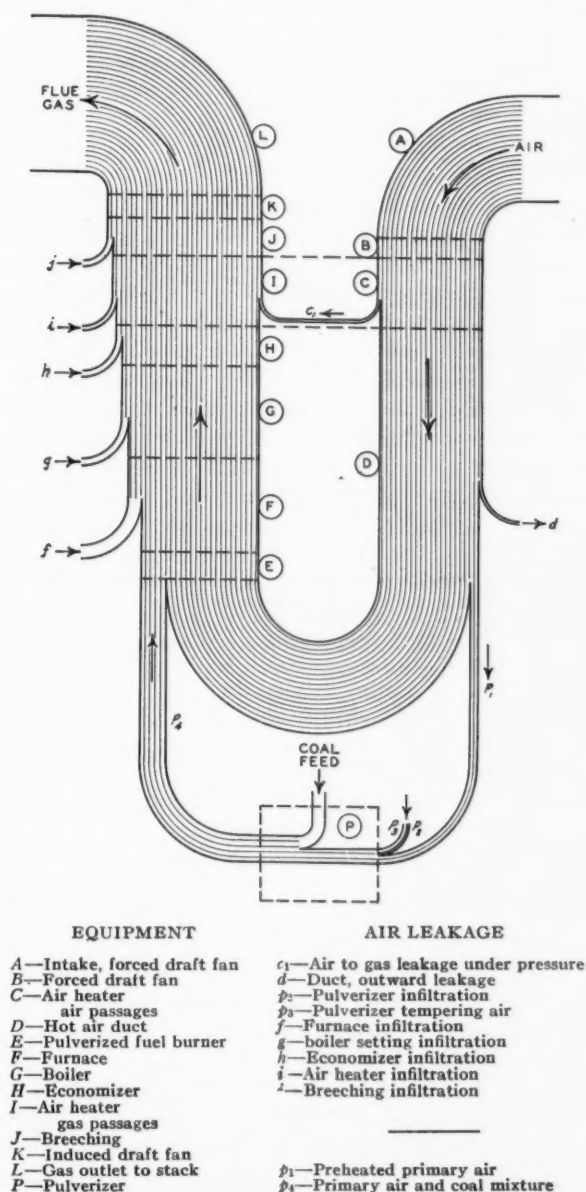


Fig. 3—Mass flow stream (drawn approximately to scale in pounds per hour, or pounds per pound of fuel) of air, fuel and products of combustion in a complete pulverized fuel fired steam generating unit

### The Particular Problem of Boiler and Furnace Infiltration

The foregoing methods enable the amount of air infiltration to be determined in pounds per hour by subtracting the mass flow, in pounds per hour, at the upstream station from that at the downstream station. These methods cannot be used for the furnace because it would be difficult to measure accurately the amount of air actually entering a furnace under control. In the case of a pulverized-fuel-fired installation the air may be supplied in three different ways commonly referred to as primary, secondary and tertiary. In the stoker-fired unit it may be delivered in two ways, windbox and over-fire; and not all the air delivered to the windbox necessarily goes into the furnace. Visualize also the problem of accurately measuring the gas weight or even the true average gas composition leaving the furnace. Furnaces have an outlet area, which corresponds to the gross passage area as the gases enter the boiler tubes, of 200 sq ft even in rather small units, 500 sq ft in moderately sized units, and about 1500 sq ft in one large unit now being installed. Imagine the problem of measuring with any accuracy the average temperature, CO<sub>2</sub> or velocity of the gases leaving such a furnace. And since the furnace outlet is the boiler inlet it is almost equally difficult to segregate boiler setting infiltration from that of the furnace. The measurement of gas composition is much more variable here than at the boiler outlet due to the mixing effect of several changes of direction in the boiler passes.

#### Air-heater Heat Balance Used to Determine Infiltration

Therefore, the furnace and boiler infiltration present a particular problem in measurement which may be solved in some instances, strangely enough, by the air-heater heat balance. The manner in which this is accomplished may best be understood by reference to Fig. 3 which diagrammatically depicts the mass-flow stream, in pounds per hour or pounds per pound of fuel, of air, fuel and products of combustion through a complete steam-generating unit, and indicates all the important sources of leakage and infiltration of air and its effect. This is shown for a direct-fired, pulverized-fuel installation using forced-draft turbulent burners and passing preheated air through the pulverizer. The calculations from which the diagram is drawn are given in Table II and will be roughly correct for an average unit evaporating 100,000 lb of steam per hour with 85 per cent overall efficiency, burning any bituminous coal, with other conditions as tabulated, and operating somewhere near its maximum capacity.

In Table II the infiltration into those parts of the steam-generating unit, where the pressure is below atmospheric, has been accounted for except that into the furnace. Referring to Fig. 3 the leakage represented by  $p$ ,  $h$ ,  $j$  and  $(i + c_1)$  may be measured by one or more of the methods previously discussed. The item  $g$ , may be measured only approximately, for reasons already mentioned, but the item  $(g + f)$  may be quite accurately determined from the air-heater heat balance on a pulverized-fuel installation since the leakage,  $d$ , from a properly constructed steel air duct will be negligible.

By the time the flue gas reaches the boiler outlet its temperature has been reduced to between 500 F and 1000 F, its composition is fairly uniform, and the cross-section of its flow path not nearly as great as it was enter-

ing the boiler. The average gas composition may, therefore, be accurately determined and the total air supplied up to the boiler outlet may be calculated from the characteristics of the fuel as plotted in Fig. 2. This consists of the secondary air, plus primary air, plus furnace infiltration, plus boiler setting infiltration. The secondary air, as indicated by Fig. 3, is all passed through the air heater but the primary air may consist of some cold tempering

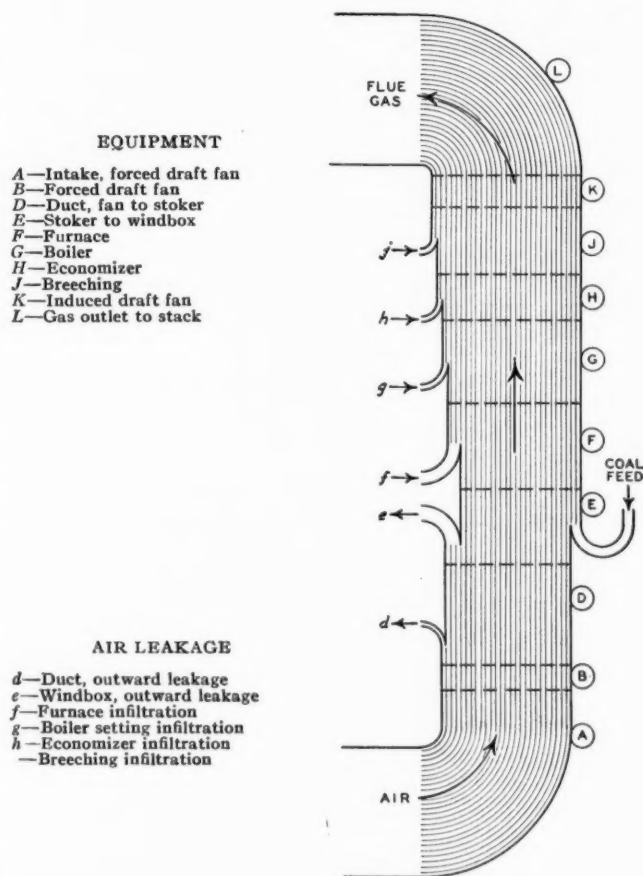


Fig. 4—Mass flow stream (drawn approximately to scale in pounds per hour, or pounds per pound of fuel) of air, fuel and products of combustion in a stoker fired steam generating unit without an air heater.

air if the air preheater is large and the coal not extremely wet. The tempering air may readily be measured with an anemometer or orifice and if the weight of air passed through the heater were known the combined infiltration of boiler and furnace would be known.

The weight of air passed through the air heater could, of course, be measured by arranging an inlet duct with an orifice to the forced-draft fan intake; or it might be measured at the air heater outlet by means of pitot tubes and thermometers. It is much simpler, however, to use data which must be obtained anyway for the heat balance of various parts of the unit. For instance, in a test in accordance with the A.S.M.E. Power Test Code the gas analysis and temperature entering and leaving the air heater would be measured. The heat absorbed per pound of coal from the gas in passing through the air heater may be represented by the following equation:

$$H = (W_1 \times C_1 \times t_1) - (W_2 \times C_2 \times t_2) \quad (7)$$

In which  $H$  is the Btu per pound of fuel absorbed from



gas;  $W_1$  and  $W_2$  are the total weight of gas per pound of fuel entering and leaving the heater, respectively;  $C_1$  and  $C_2$  are, respectively, the mean specific heats, Btu per pound per degree Fahrenheit at constant pressure between zero Fahrenheit and  $t_1$  and between zero Fahrenheit and  $t_2$ ;  $t_1$  and  $t_2$  are, respectively, the average gas temperatures entering and leaving the air heater, in degrees Fahrenheit. This equation makes due allowance for heating the air infiltration up to the temperature  $t_2$ ; so in a large well insulated heater practically all of  $H$  must be absorbed by the air in accordance with the following equation:

$$H = W_a \times C_3 (t_4 - t_3) \quad (8)$$

in which  $H$  is the Btu per pound of fuel absorbed by the air in the air heater;  $W_a$  the pounds of air per pound of fuel leaving air heater;  $t_3$  and  $t_4$  are respectively the temperature of the air entering and leaving the heater; and  $C_3$  is the specific heat of air, Btu per pound per degree Fahrenheit. Combining equation (7) and equation (8), the weight of air per pound of fuel may be determined from the measured or calculated test data. For accuracy the values of  $C_1$ ,  $C_2$  and  $C_3$  should be calculated from the analysis of the gas, including the water vapor present. Neither equation (7) nor (8) agree in result with the equation given in the A.S.M.E. Test Code for the reason that the Code assumes the weight of air passed through the heater ( $W_a$  in equation 8) is identical with the weight of air calculated from the furnace gas analysis and supplied up to the point where the gases leave the furnace. This assumption will seldom be true with oil, gas or pulverized fuel firing and may, under certain conditions, result in an error of as much as 50 per cent in the value of  $H$ , as will be explained subsequently.

The weight of air passed through the air heater, calculated from the air heater heat balance in accordance with equations (7) and (8), is generally expressed as a certain percentage of the "air for combustion." "Air for combustion" is a vague term and, strictly speaking, should refer only to the air theoretically required to burn the fuel. Consulting engineers and purchasers of power-plant equipment use the term very loosely in their specifications. In the writer's opinion it should be more clearly defined as, for example, by writing "air for combustion leaving the boiler" or "air for combustion at the boiler outlet  $CO_2$ ." The term excess air is very little used now, it being customary for manufacturers to predict or guarantee the average  $CO_2$  and CO content of the flue gases at some specific point such as the boiler damper or air heater outlet or both.

The use of  $CO_2$  as an index of excess air is quite logical since, speaking in such terms, one then talks the language of the operators and firemen who read the recording  $CO_2$  meter or operate the Orsat. The writer prefers therefore to express the weight of air passed through the heater, and also the quantities of air which leak into the gas stream at various places, in per cent of air for combustion measured at boiler outlet  $CO_2$ . Thus, if we were checking up on the unit for which data is given in Table II and consisting of the apparatus indicated by Fig. 3, we might determine  $W_a$  from equation (8) to be, say 10.6 lb or  $10.6/13.18 = 80$  per cent of the air measured at the boiler outlet  $CO_2$ . Assuming  $d$  in Fig. 3 is 1 per cent, we find that furnace and boiler setting infiltration must be  $[13.18 - (10.6 - .13 + 0.60)] = 2.11$  lb or 16 per cent.

As indicated by Table II and previous discussion, the boiler setting infiltration may be approximately determined. Segregated as 0.75 lb per lb of fuel or about 6 per cent this leaves about 10 per cent for furnace infiltration. This set-up represents average conditions for the average direct-fired steam generating unit operating at near maximum capacity. For the same unit operating at reduced capacity the figures would be considerably different.

In Part I of this series it was mentioned that the method of firing and the fuel affect the rate of infiltration. They affect also the measurement of that part leaking into the furnace. The air heater heat balance will generally be found satisfactory as a means of determining furnace leakage as explained above for forced-draft, oil- and gas-fired units but not for stoker-fired units. The reason for this is that the outward leakage of air from the stoker windbox is sometimes appreciable and entirely unmeasurable. It is undoubtedly greatest from the windbox of the multiple-retort type because the air pressure required is high and there are numerous rods, controlling air dampers and coal rams, which pass through the windbox walls.

Fig. 4 shows the mass flow diagram for a stoker-fired unit. It will be apparent that the determination of furnace air infiltration is impossible. The author has worked up numerous sets of test data on stoker-fired units and very often finds that from 10 to 20 per cent more air was passed through the heater than the total weight supplied up to the boiler outlet. Such figures indicate either a huge amount of leakage from the stoker windbox and ducts, or large errors in the measurement of the air heater temperatures.

#### *Conditions with Storage System*

The system of air supply is further complicated when the storage system of pulverized-fuel firing is used. In this case the air used to sweep the coal from the pulverizer must be removed from the coal-air mixture and either vented, partly or wholly, to the atmosphere or returned to the mill for recirculation. When the pulverizing equipment is at a remote distance from the boiler furnace the air used in the process of pulverization may not affect the conditions of operation of the furnace. However, when the pulverizers are in the same building with the boilers, preheated air is often passed through them for the purpose of removing moisture from the coal. In such a case a quantity of air at least equal to the weight of preheated air taken into the pulverizer must be vented continuously from the system. If this air is vented to the furnace, conditions are practically the same as if this air had not gone to the pulverizer, with the exception that the weight vented will be greater than that delivered to the pulverizer by the amount of all infiltration into the pulverizer system. However, if the air so used is vented to the atmosphere or the stack, then the conditions will be analogous to those for the stoker-fired unit illustrated by Fig. 4.

It has not been the intent of this present article to discuss the magnitude of infiltration; that will be done in the next and final installment of this series. It is to be hoped, however, that the reader has gained the impression that air infiltration measurement is not a simple and accurate or standard procedure, and that the most important and largest items are the most difficult to measure.



# Patents\*

By GEORGE RAMSEY, New York  
Patent Lawyer, Member A.S.M.E.

## PART XV

### Interference Procedure (Concluded)

#### *Strength of Evidence*

THE evidence in interference cases, like the evidence in all litigation, to be effective must be sufficiently strong under proper legal rules, to establish the facts sought to be proved. The Rules of Practice of the Patent Office provide certain prescriptions as to the taking of testimony and the evidence which is not taken in compliance with these Rules will not be considered at final hearings. However, mere technical objections will not be noticed unless they have resulted in a substantial injury to the party raising the objection. Where a technical objection has worked or tends to work a substantial hardship, the objector must give notice to the Patent Office and to his opponent that he will rely at the final hearing on the technical rejection unless the objection is removed. Such objections and notice are usually made on the record as soon as the objection arises and usually this is sufficient notice to an opponent and to the Patent Office. In aggravated cases, it may be desirable to give special notice both to the opponent and to the Patent Office. The generally established rules of evidence apply in interference cases as to the strength and weight of the evidence.

When an interference reaches the testimony stage, the ultimate facts sought to be proved by each party is priority of invention and each party introduces evidence to this end. The evidence may be wholly oral as to certain phases of the case. By oral evidence is meant evidence which is not supported by a physical exhibit or documentary evidence. It frequently happens that there are no existing documents or physical exhibits to support conception and disclosure. Disclosure is often made during general conversation or on a railway train or in some other place where facilities for sketching or illustrating the invention by physical objects, which may be retained as an exhibit, is not practical and sometimes sketches made on an occasion of this kind are not considered at the moment as being of much value and are either thrown away or lost. Under these circumstances, all that can be done is to take the testimony of the parties cognizant of the facts and to have the proofs as full and complete as possible.

It is well to bring out collateral facts incident to the occasion when the disclosure was made. These collateral facts usually have substantial value in establishing

This concludes the series of articles which Mr. Ramsey has written covering the complete Patent Office Procedure, including both ex-parte prosecution of applications and inter-parties prosecution under Interference Procedure. The present article deals with the strength of evidence in an interference case, with the general rules that testimony should be corroborated, and with the procedure necessary for preparing for final hearing in an interference case. It goes in a general way into court proceedings which relate to the interference practice, including appeals to the Court of Customs and Patent Appeals in Washington, D. C.; or a suit may be brought under Revised Statute 4915 and an appeal therefrom may be taken to the Circuit Courts of Appeal.

the date of the disclosure. They also may explain the reason for absence of documentary proofs. If sketches were made at the time of the disclosure and then lost, it is sometimes desirable to have the witness make a sketch at the time of giving the testimony, which sketch he is able to identify as being similar to the sketch or sketches which were made at the time of disclosure. The sketch made during the taking of testimony is of itself not competent evidence, but it is illustrative of the facts to which the witness is testifying.

Proofs which rest solely on oral evidence are subject to all legal presumptions which tend to weaken this kind of evidence, such as for example, the frailty and inaccuracy of human memory, the liability of the witness to have mentally confused an earlier conversation with a later one and further tendency of a witness to take sides unconsciously in the controversy. A witness may refresh his recollection by reference to some documentary evidence which may be independent of the matter in issue. Under these circumstances, the witness may testify that by reference to such a document, his recollection is refreshed. This reference to the document does not, however, make the document admissible as evidence. It is not the document that is proof of the case, but it is the recollection of the witness.

Where a witness refers to a diary to refresh his recollection, but does not offer the diary in evidence, his opponent has no right to inspect pages other than those specifically examined by the witness. The opponent might obtain access to the diary by a subpoena duces tecum, thereby making the witness his own witness but this procedure might be dangerous because

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if the diary contained damaging statements, the person introducing the same as evidence would not later be permitted to impeach his own testimony.

It is usual that the proofs as to conception and early disclosure are the weakest portions of the testimony because, at this stage, it often happens that the inventor had not as yet fully realized the importance and the value of the invention which he had conceived. This situation is recognized by the Patent Office and usually less strict proof is required as to conception and disclosure than is required when it comes to reduction to practice, or, in other words, completion of the invention by actual test of a completed device. However, this statement does not mean that any kind of proof can be used to establish conception and disclosure. It has been repeatedly held that the testimony of the inventor alone is not sufficient. It has been repeatedly held that mere general statements of witnesses, which statements might define an invention old in the art as well as the invention in contest will not be accepted. The proofs must be clear and to the issue. Clear, concise, oral testimony may be accepted. Of course, oral testimony supported by documentary proofs is much more satisfactory.

When it comes to the proof of actual reduction to practice, the burden becomes heavier to prove the case clearly and unmistakably. It is practically essential that physical exhibits shall be produced. If the complete physical exhibit has been lost or destroyed, it often happens that parts of the mechanism may be found, which should be made physical exhibits. If parts cannot be found, it sometimes is advisable to make up a duplicate which witnesses can identify as being identical with the lost original. It occasionally happens that the invention in issue may be of such character or size that its physical embodiment cannot be brought to the Patent Office. Under these circumstances, it is advisable to produce duly proved and authenticated drawings or photographs. It is not unusual that methods and processes cannot be carried out in the presence of the officials of the Patent Office and moving pictures have been accepted when duly supported by testimony. In a case where the issue was a method in gathering glass, the operation was carried out in a glass factory in the presence of both parties to the interference and moving pictures were taken of the various steps. These pictures were supported by testimony and were used as exhibits in the case. Some very large exhibits, however, have been brought to and accepted by the Patent Office.

#### *Testimony Should Be Corroborated*

It has been generally ruled that the testimony of an inventor alone is not sufficient to establish conception or disclosure. It has been held, however, that the testimony of a brother of an inventor who was dead was sufficient to establish conception and disclosure. Sometimes testimony may be corroborated by surrounding circumstances or facts but this is usually a weak situation because of the frailty and uncertainty of circumstantial evidence. The best corroboration is the testimony of other witnesses. These witnesses need not testify to identically the same fact so long as their testimony goes to the main general fact. If an invention were demonstrated to several different persons separately all within a short period of time, a situation would arise where no two corroborating witnesses could testify

to the same demonstration. However, the testimony of the several witnesses to the same type of demonstration and the same apparatus would be sufficient to prove the existence and successful operation of such apparatus within the period of time specified.

It has also been held that where testimony although weak is of such a nature that it could easily have been rebutted if untrue, and no rebuttal testimony was offered, that the circumstances surrounding such a situation would be considered as corroborative of the facts sought to be proved. The mere date on a drawing does not of itself establish that the drawing was made at that time, and it has been held that the testimony of the inventor alone as to the date on the drawing was not sufficient to establish the date. A circumstance which would have been corroborative in this case would have comprised placing the drawing in an envelope, sending the drawing through the mail and then opening the envelope with the mail date stamps thereon, before the officer taking the testimony. These circumstances would clearly have corroborated the inventor's testimony as to the date of making and mailing the drawing.

In general, the proofs to establish priority in a close case must be very strong and the facts must be established beyond a reasonable doubt.

#### *Record*

When the testimony has been taken, the officer before whom it is taken must securely seal up all the evidence, notices and paper exhibits and must attach a certificate to the envelope giving the title of the interference, the name of each witness, the date of the sealing of the package and then the package must be forwarded to the Commissioner of Patents in Washington, D. C. If the weight or bulk of an exhibit is so great as to exclude it from the envelope, it shall be authenticated by the officer before whom the testimony is taken and transmitted separately to the Commissioner of Patents. It is not unusual for parties before whom the testimony is taken to enter into an agreement on the record that the exhibits may be retained by the party offering the same, subject to inspection at all reasonable times by his opponents and that the exhibits shall be produced at the final hearing.

Any official record of the Patent Office or special matter contained in a printed publication if competent evidence and pertinent to the issue may be used as evidence at the final hearing providing due notice is given to the opposite party before the closing of the testimony. Such official record, of course, must be available to the opponent. For example, if a party gives notice that he intends to rely for some purpose upon some other pending application of the same party, such application cannot be used unless the opponent is given authority to inspect the same or such parts thereof as will be relied upon at the hearing.

#### *Printing the Record*

When the record is once filed in the Patent Office, it may be inspected by any party to the case, but it cannot be withdrawn for the purpose of printing. It may be submitted to someone specifically designated by the Patent Office to print the record under proper restrictions. Thirty-one or more printed copies of the testimony must be furnished—five for the use of the Patent Office, one for each of the opposing parties and



twenty-five for the United States Court of Customs and Patent Appeals should an appeal be taken. Where no appeal is taken, twenty-five of the copies will be returned to the party filing them. The printed copies of the junior party must be filed in the Patent Office not less than forty days before the date set for final hearing and printed copies of the record of the senior party shall be filed not less than twenty days before the day set for final hearing. The size of the printed record must be  $7\frac{5}{8} \times 10\frac{1}{4}$  in. This is substantially the size of a printed copy of a patent. The space of the typed matter on each page shall not be greater than  $4\frac{1}{6} \times 7\frac{1}{6}$  in. The paper must be opaque and unglazed and the type used must be eleven-point type.

There is an exception to the requirement of printing of the record before the Examiner of Interferences. The Rules provide that where the record does not exceed 125 letter-sized, double-space typewritten pages or the equivalent thereof, printing of the record may be dispensed with upon request. Where this happens, in addition to the original transcript, the party who does not print must file an extra typewritten copy for use by the Patent Office and also an extra copy for use by the adverse party. These extra copies must be filed within the time specified for filing printed copies.

The Patent Office Rules now require that where an appeal is taken to the Board of Appeals, the record must be printed in all cases. There seems to be no sound reason for requiring printing before the Board of Appeals where printing before the Examiner of Interferences has not been required. The Rules, therefore, will probably be changed to provide that, in the special cases specified, when a proper number of clearly legible copies have been filed, the record need not be printed on appeal to the Board of Appeals.

The Rules also provide that in any case, upon a motion supported by satisfactory proof, and where a party by reason of poverty is unable to pay the cost to print his testimony, printing may not be required. In such a case, extra typewritten copies of the record are required, one for the Patent Office and one for each adverse party. This special feature of the Rules is not often used because ordinarily, the party who has sufficient funds to fight an interference will be able to raise sufficient funds to print the record.

### *Briefs*

Where the brief does not exceed thirty pages of legal-size double-space typewritten pages, or the equivalent thereof, typewritten briefs may be submitted at final hearing, otherwise the briefs must be printed, and shall be of the same size as to page and printed area as the printed copies of the testimony. Six copies of the brief must be filed at the final hearing at least three days before the hearing. The briefs usually comprise an outline of the argument which will be made at the hearing and include full citations and decisions in support of the various legal points which each party desires to rely upon.

### *Final Hearing*

There are two procedures relative to final hearing, first, where Motions to Dissolve have been filed and heard and no testimony taken; and second, where testimony has been taken.

Where the Motions to Dissolve have been filed attacking the patentability of the claim in issue to an opponent, this party may urge the non-patentability of the claim to his opponent as a basis for a decision in his own favor upon priority of invention. This means, for example, that where a Motion to Dissolve has been filed attacking the right of an opponent to make a claim on the ground that he does not disclose the several elements called for by the claim, that if this can be established, then the party raising this point would get the patent; or if it can be shown that an opponent's device is totally inoperative, then the party raising this point would get the patent. These grounds must have been raised and argued on a Motion to Dissolve before they can be raised at the final hearing.

Motions to Dissolve at present are heard before the Examiner of Interferences and such a point will not again be heard by him at the final hearing because this, in effect, would be merely a rehearing on a point that he has already passed upon. Therefore, under these conditions, instead of setting the case for final hearing, the Examiner of Interferences will proceed directly to an award of priority in accordance with the filing dates of the parties. The party who has raised these points may, however, take an appeal from the decision of the Examiner of Interferences and these questions may be fully argued on appeal the same as if they had been decided by the Examiner of Interferences at the final hearing.

It seems somewhat illogical for the Examiner of Interferences to hear Motions on questions of patentability and right to make the claim and other questions of this kind for the reason that he does not possess the information comprising the full background of the case nor does he possess full information as to the voluminous prior art which is in the possession of the Patent Office. The Primary Examiner who examines the cases in the first place as to patentability in view of the art, etc., seems best qualified to consider these questions. It is probable, therefore, that the Rules of Practice will be changed in this regard and that such hearings and motions to dissolve will be heard by the Primary Examiner. This would seem to be the more logical procedure.

The second procedure at the final hearing is where testimony has been taken. In special cases, testimony may be taken on operativeness. Such testimony, however, cannot be taken as a matter of right but only under a special ruling of the Examiner of Interferences. Where such testimony is taken the Examiner of Interferences will set the case for final hearing and will hear arguments.

The usual case is where testimony has been taken on the grounds of priority and, under these conditions, the case is set for final hearing and an argument is presented before the Examiner of Interferences. The Examiner of Interferences is the head of a Division comprising himself and a number of assistants. Usually, an assistant is present at the hearing. It is obviously impossible for the Examiner of Interferences to consider and personally read all of the voluminous records before him. Therefore, under his direct guidance, the assistant listens to the hearing, reads the briefs and the record and formulates the basis of an opinion. This is gone over and supervised by the Examiner of Interferences and the decision is then entered in the case and copies thereof mailed to each of the contesting parties.



At the final hearing, it has been the custom of the Patent Office to interpret or construe the claims in issue in the broadest possible sense that they will reasonably support. Ordinarily, the claim is considered in accordance with the disclosure of the application in which the claim originated. Where claims have been made by way of amendment, after the interference has been declared, they are construed as broadly as the language of the claim will allow. Where claims in interference are taken from a patent, they are construed with the broadest possible interpretation in the light of the disclosure of the patent. This legal fiction as to the construction of claims in interferences is different from the construction of claims in an infringement suit. In an infringement suit, the claims are construed in view of the art of record in the file of the patent. This is a more narrow, and seems to be, a more reasonable way of construing claims. There seems to be no good reason why the issues of an interference should not be construed in the same way. However, the practice is long settled in giving claims of an interference their broadest possible interpretation regardless of the art of record in the various applications involved. It is likely, however, that the Rules will be changed to set forth that the issues of the interference are to be construed in the light of the art of record in the interference, which is the same type of construction adopted by the courts in infringement cases.

Patentability of the issue in its broad sense may not be argued at the final hearing, that is, this question may be argued on a Motion to Dissolve but if the question on the motion has been decided favorably, namely, that the issue is patentable, that settles the matter. It cannot again be re-argued before the Examiner of Interferences nor upon appeal. He will not be permitted to argue at the final hearing that he himself has no right to make the claim in issue on the ground that it does not read on his disclosure. He may make such an argument in a Motion to Dissolve but if it is decided against him, that ends this question. The only questions which can be raised at the final hearing are those which may result in an award of priority to the party who is making the argument.

#### *Appeal to the Board of Appeals*

An appeal may be taken to the Board of Appeals from the final decision of the Examiner of Interferences. No fee is charged for the hearing before the Examiner of Interferences and no fee is charged for an appeal to the Board of Appeals from decisions on interlocutory motions, such as motions to amend or motions to dissolve. However, a fee is charged on the appeal from a final decision of the Examiner of Interferences. This fee at present is \$25.00.

The notice of appeal must be served upon the opponents and must set out in succinct paragraphs the grounds upon which the appeal is taken. Ordinarily, matters on appeal can only be those which were argued before the Examiner of Interferences. This rule, however, is not hard and fast in all cases. For example, in a case where no testimony was taken but it was argued at the final hearing that the opponents' case was not a complete and operative disclosure. The application had been prepared abroad and it related to a complicated electrical apparatus having a number of circuits shown in the drawings. The opponent pointed out that

the circuits shown would not operate. The applicant attempted to correct this by submitting an amplified specification and a number of new drawings illustrating features in detail which had been illustrated only diagrammatically in the original drawings. The applicant admitted on the record that the wiring circuits in the original drawing were wrong and asked that the new corrected specification and drawings be admitted. The Examiner of Interferences refused to admit the new drawings and new specification, and, therefore, awarded priority of invention to the junior party on the ground that the senior party's original disclosure was inoperative. An appeal was taken and the applicant went back to his original specification, as it had been filed and before any amendments were made therein. He pointed out that the error in the drawings was the result of a circuit which had been wrongly connected between standard electrical instruments, and argued that this was merely a draftsman's error and that it could be corrected by anyone skilled in the art; that it was obvious to one skilled in this particular electric art to correctly connect standard instruments; and, therefore, that he was entitled to the benefit of his disclosure with the instruments electrically connected properly as they should have been. The Board of Appeals agreed that the correction did not involve invention, that it was not new matter; that it was obviously the intention of the applicant that the instruments should be properly connected; and reversed the Examiner of Interferences and awarded priority to the senior party.

In hearings on appeal, before the Board of Appeals, three members sit at the hearings and usually one is an Assistant Commissioner. As has been pointed out in connection with ex parte appeals, in the past history of the Patent Office, appeals were permitted from a decision of the Board of Appeals to the Commissioner personally. It seemed an anomaly to appeal from the decision of three Judges to a decision of one Judge. Furthermore, it was believed that the public and the Patent Office could best be served by relieving the Commissioner of this duty thereby enabling him to devote his time to the administration of the Patent Office. Therefore, a law was passed which eliminated appeals to the Commissioner. In view of this change in the law, the decision of the Board of Appeals is the final and last decision in the Patent Office.

Since the Commissioner is the head of the Patent Office, any party who feels that the Board of Appeals has made a very serious and grievous error which works a great hardship may petition the Commissioner for a review of the decision of the Board of Appeals. Such a petition would only be considered by the Commissioner in a very extraordinary case and ordinarily, would be promptly denied by the Commissioner.

The law provides two separate paths which the parties may take in an interference after a decision by the Board of Appeals. The law is specific in that a choice of the paths must be made. In the preceding history of the patent statutes, an appeal could be taken from the decision of the Commissioner to the Court of Appeals of the District of Columbia and then after this had been done, the law provided that the interference could be further tried out in a suit brought in the United States District Courts from which an appeal could be taken to the United States Circuit Court of Appeals.

The law now provides that the losing party to the

interference may either appeal to the Court of Customs and Patent Appeals located in Washington, D. C. or that he may bring a suit under what is known as "Revised Statute 4915" before a United States District Court in which his opponent resides.

#### *Appeals to the Court of Customs and Patent Appeals*

Where an appeal is taken to the Court of Customs and Patent Appeals, a petition addressed to the Court, setting forth briefly that the party has complied with the requirements of the law entitling him to an appeal and praying that his appeal may be heard and, for the reasons assigned therefor, to the Commissioner, must be filed in the Clerk's office of the Court. The reasons for the appeal must be filed with the Commissioner of Patents and will be made part of the record but should not be repeated in the petition for the appeal.

The petition of an appeal and a certified copy of the record must be filed with the Clerk of the Court within forty days, exclusive of Sundays and legal holidays, from the date upon which the reasons for appeal were filed with the Commissioner of Patents. The time for filing the certified copy of the record may be enlarged by the Commissioner of Patents upon good and sufficient cause to some definite and fixed date. The Commissioner of Patents, through a properly designated subordinate, makes up the transcript of record on appeal.

The counsel for the respective parties, in order to reduce the cost of appeals, may, subject to the approval of the Commissioner, agree to a statement of facts of the case setting forth the questions raised on appeal and only so much of the evidence as may be necessary for decision on such question. Such a statement must be signed by counsel and filed in duplicate in the Patent Office. When so filed and accepted by the Patent Office, one of the duplicates together with the decisions of the Patent Office, shall constitute the record on appeal and shall be certified to the Court by the Patent Office.

The transcript of record submitted to the Court is printed under the direction of the Clerk of the Court. Before the record is printed, the Clerk causes an estimate of the cost of printing to be submitted to the party docketing the case and this amount must be paid within thirty days. If there is a cross appeal and the amount is not paid within the thirty-day period, the Clerk will notify the adverse party and he must pay the amount within ten days, but if neither party pays the amount, then, the appeal is dismissed.

The Court or any Judge may, for good and sufficient cause in support of a motion, extend the time for printing or, where the time limit of printing is reached during the summer recess of the Court, the amount of the estimate may be paid on or before September 1st of the year in which the appeal was taken. The printed transcript is of the same size as the printed record in the Patent Office and the printed record in the Patent Office is usually bound up as a part of the transcript of record on appeal. The Clerk of the Court prints only such additional papers as were of record in the Patent Office that were not included in the original printed record before the Patent Office.

Ordinary documentary exhibits transmitted to the Clerk of the Court and certified as a part of the record in the case are printed as a part of the printed transcript of record unless the nature of the documentary exhibit is such that it is impracticable to reproduce it in printed

form, in which case it will be received by the Court as a physical exhibit. Briefs before the Court must be printed and be of the same size as the record in the Court.

The appellant is required to file fifteen copies of his printed brief within forty days after the record has been printed and the appellee must file his brief within thirty days after the filing of the appellant's brief. Three copies of the briefs must be served upon opposing parties at the time when they are filed.

All models and physical exhibits forming a material part of the evidence taken in the Patent Office must be filed in the Court at least three days before the case is heard.

At the hearing on the case, forty-five minutes for argument is allowed by the appellant and thirty minutes for the appellee, but not more than two counsel shall be heard for each party except by special leave of the Court.

This Court consists of a presiding Judge and four Associate Judges who are appointed for life by the President of the United States by and with the consent of the Senate. Any three members of the Court shall constitute a quorum and the concurrence of three members shall be necessary to any decision. This Court will not consider any point that is raised for the first time on appeal before it. It will only pass on matters which were raised before the Board of Appeals in the Patent Office.

A decision by the Court of Customs and Patent Appeals is final and conclusive as between the parties to the interference. While no Commissioner of Patents has ignored the findings of this Court, it would appear that the findings of the Court are merely advisory so far as the Patent Office is concerned. This Court is what is known as a Legislative Court, that is, it is not specifically provided for by the Constitution, but was created through legislative action of the Congress. The decision of the Legislative Court may not be binding upon an Executive Department. It is doubtful, however, that this question will arise because the Commissioner of Patents will likely always follow the decision of the Court in a particular case.

#### *Proceeding Under R. S. 4915*

As previously stated, the losing party to an interference may choose to continue the contest before a United States District Court. This is known as the proceeding under Revised Statute 4915, but if the party has filed an appeal to the Court of Customs and Patent Appeals, then under the law he cannot proceed under Revised Section 4915. However, if his opponent has appealed to the United States Customs and Patent Appeals, he may within twenty days after his opponent has taken the appeal, file notice with the Commissioner of Patents that he elects to have all further proceedings conducted as provided in Section 4915 of the Revised Statutes. Upon such notice his opponent must within thirty days file a bill in Equity under provision of R. S. 4915, and the further proceedings are then conducted under the provision of this law.

The proceedings under Section 4915 comprise the filing of a bill in Equity which is filed in the United States District Court in which the opponent resides. The opponent must file an answer in accordance with the equity procedure of the Court. The case now proceeds as a new original suit and the parties have a right to take testimony in open Court or in such other manner



as is prescribed by the Rules and the laws governing the procedure of the District Court in which the suit is filed. The parties are not limited to raise points that were raised before the Board of Appeals in the Patent Office. Entirely new grounds may be taken or the grounds in the Patent Office may be amplified. The moving party must, however, direct his case primarily to getting a patent for himself. He cannot attack his opponent on any ground that would, if successful, destroy his own right to a patent. It is an original suit, just as though no testimony had been taken in the Patent Office. However, the law specifically provides that the record in the Patent Office may be admitted in whole or in part subject to such conditions as to further examination of the witnesses, etc. as the Court may impose. The exhibits, etc. comprising a part of the record in the Patent Office will be received by the Court with the same force and effect as if the testimony and exhibits had been originally taken and filed in the suit in Court.

#### *Appeal to Circuit Court*

An appeal may be taken by the losing party from the decision of the United States District Court to the United States Circuit Court of Appeals. The procedure governing this appeal is that which governs the appeals in the United States Courts and the decision of the United States Circuit Court of Appeals is final. From the authorities it would appear that a decision under R. S. 4915 by the United States Courts is binding upon the Commissioner of Patents. There does not appear to have been any case where the Commissioner of Patents refused to recognize such a decision, but it would appear from the law that the decision of a Constitutional Court (that is, a Court specifically provided for in the Constitution, as are the United States District Courts and Courts of Appeals) is not subject to re-examination by administrative departments. Therefore, it would appear that the Commissioner of Patents would be bound by such a decision.

The proceeding under Section 4915, since it follows the general equity proceeding of the United States Courts, leads into discussions of Federal Court practice which are beyond the scope and intent of these discussions, and, therefore, only a brief outline has been given as to this procedure.

Where a patent has been involved in an interference proceeding and is lost on the ground of priority, it is advisable to promptly disclaim the claims which were lost in interference or to reissue the patent and omit the claims that were lost. Unless this is done promptly, the law of disclaimers (which has been previously discussed) is such that the patentee may lose the benefit of other claims in the patent which were not involved in interference and which otherwise would be valid.

#### *Conclusion*

The foregoing concludes the analysis of the procedure to obtain a patent in both ex parte and inter parties cases. In other words, the entire scope of Patent Office procedure has now been analyzed. There has been, from time to time, various proposed legislation to modify or change the present patent system. Its past history, however, has so entrenched its position that no successful fundamental change has been made in substantially the past hundred years. It would seem doubtful if any radical change in the system will be

made in the near future. The growth of the arts and the administrative business of the Patent Office requires administrative changes from time to time which do not seriously affect the fundamental basis of the system. It is likely that slight changes will be made from time to time to the Rules of Practice, and some of the details of procedure which have herein been discussed as based upon the present rules, may in specific cases, become obsolete. There appears, however, to be no substantial reasons for serious fundamental changes.

Many encomiums have been written on patent system, but it seems fitting to conclude with the statement that it is one of the essential basic foundation stones of our industrial and commercial world, and will endure as long as life, liberty and property rights are secured to individuals by the fundamentals of our Government.

### **Central Station Output Up**

The week ending March 31 showed the highest central station output for the United States thus far for this year, namely, 1,665,650,000 kw. This represents an increase of 18.8 per cent over the corresponding week of 1933, 13.8 per cent over that of 1932 and only 1.4 per cent under that of 1931. The greatest increased use of electricity was recorded in the central industrial region where the percentage over 1933 was 27.4. New England is also showing a marked increase. These figures may be regarded as a very good index of industrial recovery.

**B. L. Spain**, who has been for the past twenty four years with the General Electric Company at the West Lynn works as manager of turbo-blower sales, is now connected with Ingersoll-Rand Company as Manager of the Turbo-Blower Department. He will be located at the General Offices, 11 Broadway, New York.

**E. W. Wagenseil** has recently been appointed General Sales Manager of the Hagan Corporation and its subsidiaries The Buromin Company, Hall Laboratories, Inc. and Calgon, Inc. Previous to joining the Hagan Corporation Mr. Wagenseil was in charge of air pre-heater sales for the Blaw-Knox Company.

**William F. Sailer**, formerly with Alco Products, Inc. and the Griscom-Russell Company has recently joined Steel and Tubes, Inc., and will be located in the Brooklyn, N. Y., office. His work will be concentrated on the Marine and oil refinery fields.

**Maxfield Pease** has been appointed Cleveland representative of H. O. Swoboda, Inc. of Pittsburgh and will handle industrial heating equipment.



# Causes and Prevention of Calcium Sulphate Scale in Steam Boilers\*

WITHIN recent years there has been much discussion as to the possibility of maintaining the desired sulphate ratios without causing calcium sulphate scale formation, especially at higher steam pressures. The A.S.M.E. Boiler Code Committee in 1932 made the following recommendation:

Operating evidence supplemented by laboratory work indicates that if not less than the following ratios of sodium sulphate to total sodium hydroxide and sodium carbonate alkalinity calculated to equivalent sodium carbonate are maintained in the boiler water, caustic embrittlement will be inhibited:

Working pressure of boiler, lb gage	Sodium sulphate	Total sodium hydroxide and carbonate alkalinity calculated to equivalent sodium carbonate
0 to 150	1	to 1
150 to 250	2	to 1
250 and over	3	to 1

If this recommendation is followed, the sulphate becomes too high for the carbonate, and scale would be predicted by the older theory. However, in many instances ratios of over 3 are being maintained in plants at higher pressures, calcium is entering the feedwater in various amounts, phosphate is not being added, the amount of CO<sub>2</sub> is decidedly low, yet scale is not a problem.

These discrepancies between theory and operating conditions may be explained by lack of sufficient data to formulate theories which hold at the higher pressures.

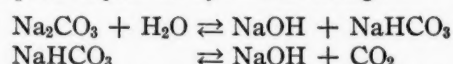
To obtain data as to the solubility of the calcium salts alone, and in the presence of positive and negative ions, over the entire pressure range of boiler operation, the investigation was divided into five parts: (1) laboratory solubility studies; (2) laboratory experiments on decomposition of sodium carbonate solutions; (3) scale formation in laboratory boiler; (4) scale prevention in laboratory boiler; (5) scale prevention in industrial power plants.

This investigation was directed primarily to the study of calcium sulphate scale formation and prevention. No attempt was made to study magnesium, silicate or other forms of scale. A research is now being conducted as to these forms. The solubility tests were run at 360, 405, 470, 540 and 600 F, corresponding approximately to 150, 250, 500, 1000 and 1500 lb gage pressure. They indicated that:

1. Solubility of calcium carbonate decreases with increase in temperature.
2. Solubility of calcium carbonate in the presence of sodium carbonate or hydrate is practically zero at the temperatures studied.
3. Solubility of calcium sulphate is not directly proportional to the sulphate in solution.
4. Calcium sulphate as a solid phase cannot exist in equilibrium with solutions containing over 30 ppm of sodium carbonate, even at 1000 lb per sq in.
5. The old calculated ratios CO<sub>3</sub>/SO<sub>4</sub> to prevent calcium sulphate formation as a solid phase are high.

As to the decomposition of sodium carbonate solutions, the investigation showed:

1. The principal controlling factor is the partial pressure of carbon dioxide in the vapor phase which, in turn, depends on the amount and availability of potential carbon dioxide in the feedwater.
2. The effect of boiler pressure decreases with a decrease in carbonate content of the feedwater.
3. For the range of steaming rates covered in the tests, boiler rating does not appear to be a factor.
4. Total alkalinity is a factor, the extent of decomposition decreasing with increase in alkalinity.
5. Decomposition phenomenon appears to take place in two steps as expressed by the following:



6. Complete decomposition cannot be attained even in the steaming boiler.
7. The usual boiler water analysis indicates less hydroxide than probably exists during operation.

In the laboratory boiler it was found that calcium sulphate scale formation occurs at an almost constant rate at 150, 250 and 500 lb pressures; at 1000 lb it forms about one-third as fast as at 150 lb (for a constant rate of heat transfer); while at 2000 lb it forms only about one-tenth as fast. Furthermore, the rate of calcium sulphate scale formation appears independent of the amount of calcium sulphate entering the boiler, or the amount of sludge (within reasonable limits).

The investigation indicated that the formation of calcium sulphate scale can be prevented, up to 2000 lb per sq in., by the presence of more than 30 ppm (1.79 g per gal) of sodium carbonate; and that the carbonate content, necessary to prevent sulphate scale, is independent of sulphate concentration within the limits of concentrations carried in the average high-pressure boiler.

To check these investigations against results in actual operation, samples of boiler waters were collected from a large number of power plants operating at various pressures and with various types and amounts of make-up water, systems of water treatment, etc. Analyses of a typical group of these are given in the Table. These plants were all classed as potentially scale-forming under the older theories. Plants C, D, E and F have all shown at least one year's (and one over five years') operation free from scale without using the phosphate treatment.

ANALYSES OF BOILER WATERS FROM PLANTS NOT HAVING SCALE DIFFICULTIES

Plant	A	B	C	D	E	F
Press., lb per sq in.	160	225	250	450	400	700
NaOH, ppm.	200	90	247	275	144	103
Na <sub>2</sub> CO <sub>3</sub> , ppm.	26	29	64	50	42	8
Total alkalinity, ppm.	291	148	402	415	233	144
Na <sub>2</sub> SO <sub>4</sub> , ppm.	3100	5030	775	1271	3350	1130
NaCl, ppm.	125	692	...	...	1240	190
Na <sub>2</sub> SO <sub>4</sub>	10.6	34.0	1.93	3.08	14.4	7.8
Total alkalinity CO <sub>2</sub>	.007	.0047	.0685	.0326	.01	.01
SO <sub>4</sub>	10	20	90	20	20	2
Per Cent makeup.	50	290	10	10	10	2
Hardness of makeup water, ppm.	50	290	10	10	10	2

\* Abstract of report of an investigation conducted by Prof. Frederick G. Straub at the Engineering Experiment Station, University of Illinois, in cooperation with the Utilities Research Commission, and printed in full in Bulletin No. 261.

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\* The price of this book after May 1st will be \$9.00.

## 2—American Society of Heating and Ventilating Engineers Guide, 1934

862 pages 6 x 9 \$5.00

The *A.S.H.V.E. Guide 1934* is just off the press and is ready for distribution. The Technical Data Section of this edition has been enlarged to include newly developed data that are vitally important in meeting the present-day demands of engineers who devote their time to heating, ventilating and air conditioning practice. From the practical experience of members, as well as from available research sources, useful facts have been gathered and incorporated in the forty-two chapters which have been arranged for convenient reference. An extensive index has been included to aid the reader. The text is prepared for engineers, architects, contractors and students who are designing, operating, specifying, installing and studying systems and apparatus, the functions of which are to create comfort and to improve the efficiency of processing.

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The book is unique. It is authoritative and should be carefully read by all high-school students who contemplate engineering as a career. Parents and teachers will find it not only informative but of invaluable assistance in guiding the student and judging his fitness.

## 5—Book of A.S.T.M. Tentative Standards—1933 Edition

1136 pages 6 x 9 Price: \$7.00

This annual publication of the American Society for Testing Materials contains all tentative specifications, methods of test and definitions of terms issued by the Society covering engineering materials and the allied testing field. Although in the trial stage of standardization procedure, these tentative standards, embodying the latest practices, find important application and are widely used in industry.

The 1933 edition of this book contains 223 tentative standards. Of these, 47 are published for the first time, while some 41 were revised in 1933 and are given in their latest approved form.

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## 6—The Book of Metals

By Donald Wilhelm

332 pages Price \$4.00

This book is typical of several others published in recent years in that it discloses the principles and practices of a thoroughly technical industry in such form that it is just as easily assimilated by the layman as by the technician.

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# EQUIPMENT SALES

## Boiler, Stoker, Pulverized Fuel

As reported by equipment manufacturers of the Department of Commerce, Bureau of the Census

### Boiler Sales

Orders for 52 water-tube and h.r.t. boilers were placed in February

	Number	Square Feet
February, 1934.....	52	153,270
February, 1933.....	23	59,767
January to February (inclusive, 1934).....	98	284,995
Same period, 1933.....	57	196,276

#### NEW ORDERS, BY KIND, PLACED IN FEBRUARY, 1933-1934

Kind	February, 1933		February, 1934	
	Number	Square Feet	Number	Square Feet
Stationary:				
Water tube.....	13	48,816	31	129,191
Horizontal return tubular..	10	10,951	21	24,079
	23	59,767	52	153,270

### Mechanical Stoker Sales

Orders for 74 stokers, Class 4,\* totaling 18,867 hp were placed in February by 60 manufacturers

	Installed under			
	Fire-tube Boilers		Water-tube Boilers	
	No.	Horsepower	No.	Horsepower
February, 1934.....	49	7,460	25	11,407
February, 1933.....	38	5,152	23	6,561
January to February (inclusive, 1934).....	149	18,235	48	19,832
Same period, 1933.....	93	13,127	36	11,341

\* Capacity over 300 lb of coal per hr.

### Pulverized Fuel Equipment Sales

Orders for 8 pulverizers with a total capacity of 33,400 lb per hr were placed in February

#### STORAGE SYSTEM

	Pulverizers				Water-tube Boilers		
	Total number	No. for new boilers, furnaces and kilns	No. for existing boilers	Total capacity lb coal per hour for contract	Number	Total sq ft steam-generating surface	Total lb steam per hour equivalent
February, 1934.....	8	..	8	60,000	2	37,000	325,000
February, 1933.....	..	..	..	..	..	..	..
January to February (inclusive, 1934).....	..	..	..	..	..	..	..
Same period, 1933.....	2	..	2	60,000	2	37,000	325,000

#### DIRECT FIRED OR UNIT SYSTEM

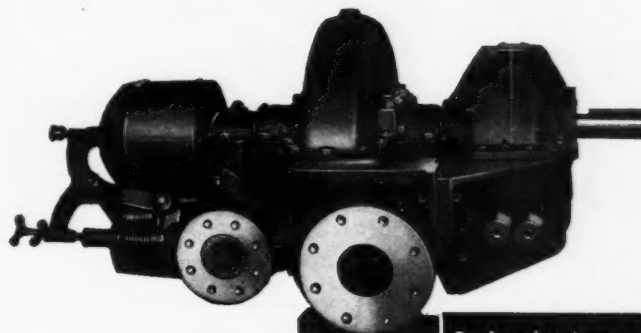
	Pulverizers				Water-tube Boilers		
	6	5	1	31,000	5	31,526	231,700
February, 1934.....	2	1	1	6,400	2	8,300	42,340
February, 1933.....	..	..	..	..	..	..	..
January to February (inclusive, 1934).....	10	7	3	56,000	8	54,706	449,200
Same period, 1933.....	12	11	1	79,000	7	72,734	697,340

					Fire-tube Boilers		
February, 1934.....	2	..	2	2,400	2	3,000	20,500
February, 1933.....	2	..	2	1,500	2	2,500	8,000
January to February (inclusive, 1934).....	2	..	2	2,400	2	3,000	20,500
Same period, 1933.....	3	2	1	2,750	3	4,000	18,300

COMBUSTION—April 1934

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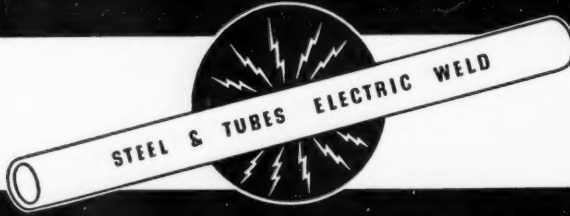
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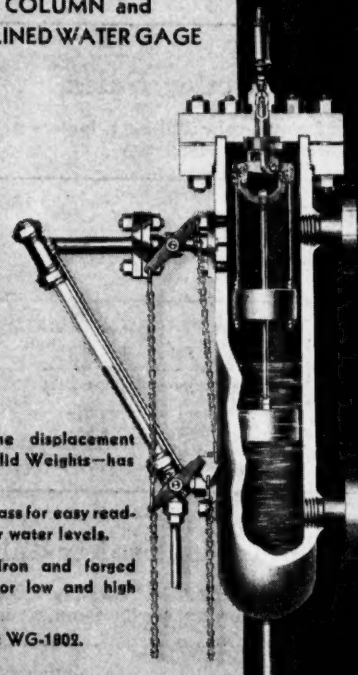
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